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BENEFITS OF COMPUTER ASSISTIVE SOFTWARE AND MINIMUM REQUIREMENTS

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ABSTRACT

Use of computer assisted software (CAS), typically combined with a problem-solving pedagogy, is common in 1) mathematics, 2) STEM, 3) writing, 4) certification exam preparation, and 5) business training. Since there are many competing CAS products, a user must know I) what *benefits* to expect from good CAS, and II) what the *minimum requirements* are. I) The *benefits* of good CAS are I-A) increased student mastery due to increased practice leading to self-efficacy, I-B) heightened awareness of objectivity, encouraging a perception that achievement is based on effort and work, thus increasing inclusion and diversity, and I-C) increased outreach to weaker students who benefit from graduated levels of problem difficulty afforded by the CAS . II) The requirements for a good CAS are II-A) a large database of problems, II-B) a classification of problems using the two-four dozen topics corresponding to the daily topics in a 15-week course syllabus, taught two to three days a week, and II-C) at least 3 levels of graduated difficulty (easy, moderate, advanced) of practice problems for each topic. Note especially that minimally the software is exclusively used for storage implying that these ideas can be implemented manually without using any computer. Simple implementation methods for creating such software are presented for both mathematics and writing courses (both education and business oriented). The assurance that the minimum requirements enumerated lead to the benefits listed is provided by the four educational pillars of Hendel.

Keywords: computer assisted software, CAS, problem databases, problem difficulty, curriculum, self-efficacy, objective assessment, remediation, four educational pillars, educational challenge, attribution, goal-setting, educational hierarchies

1. OVERVIEW

The goal of this paper is to identify what is needed to maximize instruction with specific focus on how computer assisted software (CAS) can aid this maximization.

1.1 Audiences: This paper principally applies to the instructor-student relationship but also applies more generally to any instructional situation including the training-business-staff situation, the parent-child situation, and certification.

1.2 Metrics: Typically, the assessment literature uses two metrics to evaluate good pedagogy, performance, and student satisfaction. .Performance is measured by either certification examinations, in-class examinations, or achievement of course-stated goals.

Satisfaction of the trainee or student, is also an important metric. Satisfaction has an emotional component, the extent to which the student or trainee found the experience enjoyable, as well as a cognitive component, "Does the student or trainee *feel* that they have achieved mastery?" This feeling of mastery is called *self-efficacy*, the student's belief that with their current skills they can accomplish a given task [3].

1.3 CAS: Very often, CAS is assessed independently of instruction. The questions focused on in a CAS study might include i) Is student performance increasing? ii) Do surveys of students indicate satisfaction with the software? iii) Do students or instructors identify aspects of the software simplifying the instruction process such as facilitating learning at one's own pace, facilitating learning at different schedules, or simply storage of problems and solutions?

But computers are inanimate objects; they don't by themselves increase instruction. It is rather good pedagogy, the design of curriculum, exercises, and assessment, which increases instruction. Therefore, the focus in this paper will be on whether computer assistance based on good pedagogy increases instruction. In other words, this paper asks the question, "What are the combined attributes of good pedagogy and good CAS which together maximize instruction?" Conclusions of this paper on the efficacy of CAS will always assume that the CAS is based on good pedagogy which is already present in the course offering.

It is interesting that meta-studies of CAS, for example [1] which reviewed 40 CAS studies, very often do not begin, as we have in this paper, with a discussion of the underlying pedagogy that mediates between the CAS and improvement.

1.4 Outline: The above overview immediately suggests an outline to this paper. First (Section 2), we discuss good pedagogy. Then (Sections 3and 4), we identify which pedagogical practices can benefit from CAS. Finally (Section 5), we address the operational issue of implementation presenting simple ideas enabling a faculty at an institution to implement CAS without excessive burden.

2. PSYCHO-NEUROLOGY AND CHALLENGE

Prior to presenting the psycho-neurological approach to good pedagogy (Sections 2.1-2.4), we briefly discuss the history of measuring pedagogic challenge and recent attempts at unification of superficially different pedagogic approaches.

The idea of pedagogical challenge was first formally introduced and defined in Bloom's seminal work [7] wherein he introduced the educational hierarchy. The hierarchy, as its name implies, is a set of stages (for Bloom there were six), with the earlier stages dealing with lower cognitive instruction involving memory and recall, while the later stages deal with higher cognitive instruction, activities such as analysis and synthesis. In this way, any piece of instruction or any piece of assessment can be evaluated as to its place in the Bloom Hierarchy. Theoretically, this should allow instructors to improve their education.

The Bloom hierarchy was followed by several other educational hierarchies from other researchers such as those of Gagne [12], Van Hiele [27], Anderson [2], and Marzano [20].

Each of these hierarchies requires training to use them. For example, the *analysis* stage in Marzano's hierarchy is indicated by such concrete activities as *sorting, classification, matching, error detection, etc.* Thus, for instructors to master the hierarchy they must first familiarize themselves with the basic levels of the hierarchy and then familiarize themselves with the sub-levels associated with each level.

The idea that these educational hierarchies might be measuring the same thing – that is, that they differ in nomenclature but not in substance – was first explicitly stated by Yazdani [29] who showed that the Gagne and Van Hiele hierarchies were equally successful in improving student performance.

Following this lead, Hendel, in a series of papers culminating in a book [14] sought to i) unify the hierarchies in terms of underlying neuro-psychological processes and ii) adhere to Ashby's criteria for mechanistic and descriptive accounts [23].

Hendel identified four educational pillars that unify the hierarchies. These pillars are simultaneously mechanistic in nature and also broad enough to capture the need for flexibility in educational delivery. The four educational pillars are:

- Executive Function (EF)
- Goal Setting
- Attribution Theory
- Self-efficacy.

2.1 Executive Function (EF): EF is neuro-psychological concept that refers to at least 8 distinct mental capacities [22]. These 8 capacities naturally combine into two distinct groups [26]. Both groups of EF have in common that they are mental activities that deal with multiple parts of the mind.

> *Open EF* refers to the capacity of the mind to solve open-ended problems. A typical example (occurring on EF tests) is the following: "You are on vacation and just noticed that a medicine you must take daily is not with you. What do you do?" There are a variety of answers to this question (i.e. it is open) which the evaluator scores according to specific criteria.
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> *Performance EF* refers to simultaneously using several *specific* parts of the mind. For example, finding the maximum of a function might involve computation and visual inspection of a graph or table. Throughout this paper, EF refers to performance EF.

EF is the name of the underlying psychological process. It is also known to educators by a variety of other names such as *multiple modalities* or *multiple representation methods.* These other referents to EF are used in the various educational standards such as those of NCTM [21], CCSS [10], Council for Educational Children (CEC) [11], and InTASC [16]. Thus, a variety of established standards advocate engaging multiple parts of the mind, that is, using EF, as intrinsic to good pedagogy.

Other individual researchers have independently discovered EF without explicitly referring to it in a neuro-psychological context. Hughes-Hallett, who significantly reformed Calculus education, advocated the *rule of four* for mathematics education, which requires that each class example and each assessment vehicle, should engage four mental areas, the verbal, visual, formal (algebraic), and computational [13, 17]. As a simple illustration, Hughes-Hallett points out the error in teaching calculus students how to obtain a maxima using formal methods, without also showing these students how to identify the maxima from a graph, table, or a verbal problem.

A good course curriculum is based on executive function. The course curriculum may model real-world phenomena using mathematical tools or more generally, the course curriculum, whether in composition writing, mathematics, or science, may emphasize the skillful use of a finite core set of techniques to address the multi-faceted problems of a particular domain.

Another name for a curriculum divided into modules with core principles is structured curriculum. Meta-studies have shown that SC *by itself, as an instructional method* (without necessarily using CA), significantly improves performance [4, 5, 6]. The Society of Actuaries provides a detailed SC for the Financial Mathematics Course [24] with 11 distinct modules each with a few submodules with each submodule focusing on a very specific skill. Both the instructor's online notes [15] as well as several software vendors such as coaching actuaries [9] base their pedagogical approach on the SOA structured curriculum.

In a typical 15-week two-days a week semester, on average, two class days are devoted to each of 11 modules with one day spent on theory and a second day on problems.

2.2 Goal Setting: Industrial psychologists use the term *goal setting* to refer to the breakup of an instructional task into a sequence of steps that maximizes goal accomplishment [18, 19]. Goal setting is classified as psychological since it studies how the sequencing of subtasks affects human motivation so as to maximize performance.

The literature on goal-setting, which applies equally to the business world, teaching, and one's personal life, is enormous. Books differ in what attributes good goal-setting should have; as many as 10 attributes are found in the literature. Hendel [14] summarizes these attributes with three key attribute categories:

- *Clear and specific* (a person can be told the goal and know exactly what is required without needing to ask questions)
- *Timely achievable* (the subgoal should be achievable in a short amount of time)
- *Challenging* (Good goal setting must be beyond a person's capacity and stretch them).

An important contribution of goal-setting is the *goal-setting paradox:* training students on unattainable goals actually improves performance. The following famous experiment is illustrative.

> Two groups of college students, Group A and Group B, were taught the moves of chess. The groups were exposed to chess problems, chess positions where a win can be achieved in a few moves; the goal of the students was to find the winning sequence of moves. The groups were presented different chess problems on two consecutive weeks. During the 1st week Group A was given exclusively difficult problems and in fact failed to find solutions; contrastively, Group B was given exclusively easy problems and attained high success scores. On the following week, both groups A and B were given identical sets of problems which consisted of problems rated easy, moderate, and difficult. Group A which previously had failed attained superior scores to Group B which previously had done well. The paradox here, is that the 1st-week success of Group B did not improve learning while the 1st-week failure of Group A did improve learning [8].

This example highlights the pedagogical need to have easy, moderate, and challenging problems.

2.3 Attribution Theory: Attribution theory posits that students learn best when they perceive their evaluation as due to internal, controllable, stable causes such as effort and work [28]. Contrastively, a student does not do well if they perceive that evaluation is due to luck or whimsical feelings of the teacher. Attribution is closely related, perhaps a direct consequence, of self-efficacy a key concept in social psychology that is discussed in Section 2.4.

Attribution theory assists in formulating a core tenet of good pedagogy, *respect* for the student. Although *respect* has meaning, it is not typically mechanistically defined in the sense of Ashby [23]. However, using attribution theory, *respect* can be specifically *defined* to mean that the instructor-student relationship is based on an evaluation based on internal-controllable factors like effort and work. Contrastively, if an instructor, for example, belittles a student's chance to succeed because they are kinesthetic in their learning style and not visual or auditory, then the instructor has communicated to the student that his/her success depends on external factors over which the student has no control, namely, the instructors' preconceived notions of what a good student learning style is; the student is not being evaluated based on personal effort but rather on the whims of the teacher.

2.4 Self Efficacy: Self-efficacy is a key psychological concept introduced by Bandura [3], the founder of Social Psychology. Self-efficacy refers to the student belief that with the student's current skills and efforts (s)he can accomplish a specific task. In contrast to the Freudian theories that unconscious drives motivate people, Bandura posits that self-efficacy is the single most important driver of success.

Self-efficacy has well-understood drivers. There are six drivers of self-efficacy, the most important being performance successes (a.k.a. practice). Role models and verbal encouragement methods are two other important drivers [14].

The pedagogic theory of self-efficacy highlights the importance of providing students with adequate resources for performance successes. Quite simply, a large database of problems must be provided affording students the possibility of achieving performance successes and mastery.

3. COMPUTER ASSISTANCE WITHOUT COMPUTERS

Sections 2.1, 2.2, 2.3, and 2.4 characterize good pedagogy as pedagogy that:

- Is accompanied with a database of a large number of problems (Section 2.4)
- Presents at least 3 graduated levels of difficulty (easy, intermediate, and challenging) of problems (Section 2.2)
- Covers all aspects of an instructional curriculum addressing core principles and multiple modalities of presentation. (Section 2.1)
- Creates a student perception that their assessment is based on effort and work and not on whimsical biases of the teacher. Clearly, a computer administered examination or exercise, graded by a computer, has the needed objectivity to assure students that personal prejudices of instructors do not determine their grade (Section 2.3).

It is also immediately seen that these items can be accomplished both with, as well as without, computers. The computers do not instruct. They at most facilitate the implementation of these principles. More specifically:

- Most instructors construct course curricula without a computer
- There are a variety of vehicles to obtain large problem banks including, personal notes and textbooks
- Although laborious, difficulty level can be computed without computers. A traditional way of scoring problem difficulty is to regard each problem on class examinations as a stand-alone one-question test. For example, if 90% of the class correctly answered a problem it is *easy;* if only 20% answered it correctly, it is *challenging.*

However, it is clear that computers *facilitate* these tasks. Computers also have other advantages

- They allow instant online grading and storage of student quizzes
- They allow instant assessment of difficulties; this is particularly valuable if an instructor has a large class
- Computers can assess the validity of a course curriculum by confirming that a set of core principles for a particular course module allows student mastery as shown by student grades on module-quizzes.

We have already remarked, though it bears repetition, that meta-studies of CAS frequently (with some exceptions) assess CAS without simultaneously assessing the accompanying pedagogy. This omission leads to contradictory results for the efficacy of CAS. This paper predicts that a study which assessed proper pedagogy with and without CAS would show the benefits of *facilitating* pedagogical goals using CAS.

4. PERSONAL INSTRUCTIONAL ANECDOTES

This section relates the author's experience with the methods of this paper.

The author's students must prepare to take and pass the difficult Society of Actuary (SOA) Examinations [25]. The author's classes use a simple software package [9] that has a databank of questions classified by topic and difficulty.

The author constructs a syllabus such that each day of the course focuses on a single topic that can be mastered through a collection (typically 3-6) of core principles. The application of the core principles are illustrated through problems of selected difficulty in the software package.

Homework is assigned from the software package. Most of the homework is electronic. However, each class requires one written solution. The solution is exclusively graded by the presence of a solution organized around the core principles. In other words if a problem requires applying 4 core principles (for example, graphs, calculator lines, algebra, key equations) then the possible grades on the homework are 25, 50, 75 or 100 corresponding to how many core principles are correctly applied (half credit is allowed also). Nothing else, such as sloppy algebra or arithmetic mistakes are graded. This approach clearly communicates to the students the expectations of mastery by the instructor. For example, a student who correctly solves the problem but omits a graph receives a maximum score of 75. The grades on these written homework assignments correlate well with examination grades.

The author's instructions to students (after uniform teaching during the semester) are as follows:

i) To pass the SOA examination you need to score 70% or higher on 30-35-question tests consisting of questions with difficulty levels 4,5 and 6.
ii) Each student should start at a level where they achieve high scores; this might be level 1 or 4 for different students.
iii) After acquiring proficiency at a given level the student should advance to the next level (Here we expose students to the *challenge* aspect of goal-setting)
iv) The instructor (me!) is not needed unless you get stuck for a few days at a particular level and at a particular score range. This would indicate that you need some extra tips on how to approach certain questions.

Thus, the instructor becomes a *facilitator, a coach backup,* someone to come to when published solutions and instructional materials do not suffice.

Using two important metrics, performance and satisfaction, this approach works well. Students frequently pass the difficult SOA examinations upon completion of the semester. Students on a variety of evaluation vehicles including student evaluations express satisfaction with the approach.

5. OPERATIONAL IMPLEMENTATION

This section describes how a university department can implement the pedagogical methods and approach described in this paper with minimal cost and effort.

Quite simply, each semester, the department gathers final (and other key) examinations. Each problem on the final examination is stored in a database with two tags, a) the submodule addressed, and b) the difficulty level. The difficulty level may reflect a statistical approach (what percent of students achieved a perfect score on this problem; alternatively, what was the average grade) or the instructors subjective assessment).

When the number of problems reaches a few hundred, the database is ready to be used. It can provide practice to students on every course module and at every level of difficulty, and additionally can be used for classroom illustrative problems and class examinations.

6. CONCLUSIONS

This paper has presented the unusual position that computer assisted instruction can be accomplished without computers and that computers at most facilitate good pedagogy which is the true driver of success. A minimum needed for CAS is i) a detailed daily curriculum exposing students to the core principles needed to master diverse topics, ii) a large databank of problems, with iii) at least three levels of difficulty *easy, moderate, and hard.* Additionally, a university department on a limited budget can implement CAS by pooling questions from say final exams with each question tagged by a) the faculty subjective opinion of difficulty, b) the main curriculum topic, and c) the curriculum subtopic.

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