DOCUMENT RESUME

ED 464 601		IR 021 184

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TITLE	An Overview of the Research Base of PLATO. Technical Paper.
INSTITUTION	PLATO Learning, Inc., Bloomington, MN.
REPORT NO	PLATO-TP-12
PUB DATE	2002-03-00
NOTE	73p.
AVAILABLE FROM	For full text: http://www.plato.com/whitepapers.asp.
PUB TYPE	Information Analyses (070) -- Reports - Descriptive (141)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	Computer Assisted Instruction; Computer Software Development; *Courseware; *Educational Research; *Educational Technology; Educational Theories; Elementary Education; Instructional Design; *Instructional Materials; Mathematics Instruction; Reading Instruction; Standards; Teaching Methods

ABSTRACT

Professional educators demand that their methods and instructional resources be soundly based on research and theory. From its origins nearly 40 years ago, the PLATO[R] system has built the largest base of basic research on computer-based learning in the field. Beginning with research funded by the National Science Foundation and conducted at the University of Illinois and collaborating institutions, nearly 900 references on the PLATO[R] system are listed in the ERIC educational research database. This paper summarizes the research base of PLATO[R] Learning's instructional software, and describes the theoretical grounding of the curricula in the theory of reading, mathematics, and instructional design. It describes the PLATO[R] independent evaluation program and summarizes effectiveness studies performed as part of the ongoing program. PLATO[R]'s instructional design standards are described with nine tables, covering the areas of general design; standards for content/information; comparison of direct instructional models; standards for tutorials; standards for application practice; standards for problem solving activities and simulations; standards for information software; standards for tool software; and standards for tests. (Contains 77 references.) (AEF)

PLATO®

An Overview of the Research Base of PLATO

Technical Paper #12

March, 2002

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Abstract

Professional educators demand that their methods and instructional resources be soundly based on research and grounded in theory. This paper summarizes the research base of PLATO Learning's instructional software, and describes the theoretical grounding of the curricula in the theory of reading, mathematics, and instructional design.

The table below summarizes the research base described here.

Professional Standard	PLATO Learning's Research
Independent evaluations	13 studies by independent evaluators are summarized here. Evaluators are university-and research center-based experts in evaluation and technology.
Standard Evaluation Designs	A variety of standard study types are included: • Experimental Design (1 study) • Comparison Group Design (5 studies) • Pre/Post-test Designs with gains reported (6 studies) • Case study with ending achievement reported (1 study)
Standardized Tests	Almost all studies use standardized and published tests for achievement.
Gains sustained over time	The studies describe program cycles of less than 30 hours to two semesters. Program durations from 4 weeks to 4 years with sustained gains across multiple program cycles.

Professional Standard	PLATO Learning's Research
Full Implementations	Each study represents a full implementation of the PLATO courseware, using one of three flexible implementation models which have been defined for PLATO: *supplementary, complementary*, or *primary*.
Implementations well described	Implementations are fully described in the complete evaluation reports. They are briefly summarized here.
Costs well documented	Cost data, including hardware, software, support, and professional development, are provided by PLATO Learning personnel.
Similar service populations	The studies include *urban, suburban, and rural* contexts, many with *underachieving, low-income and diverse populations.*

Professional Standard	PLATO Learning's Research
Wide replication	The studies describe replication of the PLATO system across a range of settings: • *elementary, secondary, and post-secondary.* • A variety of program types, including *full implementations* in *primary* uses of PLATO (mostly self-paced, mastery model, individualized with instructor tutoring and coaching), and *partial implementations* in supplementary uses (for review and reinforcement of classroom instruction), often with a goal of standardized test remediation or preparation. • *Program sizes* range from 25-1,000 students
Replications evaluated	Each of the studies summarized here is supported by a full evaluation report. Many additional case studies (with abbreviated reports of data) are available on request.

We can make these general observations from the studies:

Improved performance on standardized tests	The greatest gains are in programs using the primary instructional model for a semester or more (at least 30 hours of use). Effect sizes, where reported, were up to 1.5, or 2 standard deviations. This represents improvements of up to 60% on achievement of standards. Supplemental programs generally produce smaller gains, but one study reported gains of over 3 standard deviations. Effect sizes were most commonly under .5, representing improvements of up to 15% on achievement

	of standards.
Improved credit recovery and dropout prevention	Improved graduation rates result in credit recovery and dropout prevention programs with up to 100% success rate.
Improved time on task leads to achievement gains	In the primary instructional model longer programs with more study of PLATO produce greater effects with significant correlations of up to +.83. While the relationships between time on task with PLATO and achievement are complex and isolation of the effects of PLATO is never a goal of these evaluations the relationship does suggest positive effects of PLATO.

Full evaluation studies, PLATO *Technical Papers*, and additional implementation reports are available from the PLATO web site, www.plato.com.

PLATO curricula are grounded in the theory of each major content area and the field of Instructional Design.

In reading, the principal influence on PLATO's curricula has been the research summarized recently by the National Reading Panel (NRP). The table below shows the relationship of the NRP's conclusions and the PLATO elementary and secondary reading curricula. A more detailed discussion is in Part 3 of this paper, and in PLATO technical papers on reading.

Key NRP Conclusion	**PLATO's Curriculum Design**
7 cognitive strategies have been validated for teaching reading comprehension. They should be applied in combination to the reading task.	These 7 cognitive strategies are incorporated in the PLATO secondary reading curriculum components which teach reading comprehension extensively. The strategies are taught as heuristics to be combined and applied to the reading task at hand. The same 7 strategies form the basis of the elementary 4-6 reading curriculum, now in development. In addition, reading is an essential skill for the

Key NRP Conclusion	PLATO's Curriculum Design
	interdisciplinary real-world problem solving activities which are part of the PLATO curricula. These activities provide real-world, motivating context and establish the need and occasion for high-level comprehension in a collaborative learning environment.
Vocabulary instruction leads to gains, and should be taught both directly and indirectly. Use of computers was found to be more effective.	PLATO's curriculum includes both direct and indirect vocabulary instruction. Direct instruction is accomplished with the *Vocabulary Builder* system, which teaches pre-reading vocabulary and SAT vocabulary, and provides a convenient tool for teachers to build their own word lists. Indirect instruction is accomplished through incorporation of a level-appropriate full online dictionary which can provide definitions for any on-screen word or any word typed in.
Fluency is a critical skill, and can be taught through a combination of guided repeated oral reading and silent reading	Guided repeated oral reading is supported in PLATO curricula at the elementary and lower level secondary courses through read-the-screen audio. This feature can be turned on or off by the instructor. Silent reading is supported at all levels through short, medium and long passages of a variety of text types, all carefully leveled using standard reading formulas.
Phonics instruction should include explicit, systematic phonics instruction and a focus on putting the letter-sound relations to use in reading whole words and passages.	A full technology-based phonics solution is beyond the state of the art, and must be implemented by instructors. PLATO elementary curricula are designed to supplement a systematic phonics program, by providing additional practice on phonics as part of the task of reading whole words, sentences and passages.
Phonemic Awareness instruction using explicit methods is the foundation of successful reading.	A full technology-based phonemic awareness solution is beyond the state of the art, and must be implemented by instructors. PLATO elementary curricula are designed to supplement a phonemic awareness program, by providing practice and reinforcement if PA at the grades 1-2 levels.

In mathematics, the principal influence on PLATO's curricula has been the research applied to develop the curriculum standards of the National Coucil of Teachers of Mathematics (NCTM) The table below shows the relationship of key trends found in the NCTM standards and the PLATO elementary and secondary mathematics curricula. A more detailed discussion is in Part 4 of this paper, and in PLATO technical papers on mathematics.

NCTM Approach	PLATO Mathematics Curricula
Learner-based: The learner discovers and constructs meaning. The learner encounters the core concepts and principles through investigation. (The teacher provides opportunities for investigation and facilitates.)	PLATO curricula support an investigation and problem-centered approach. If the instructor wishes, the modular curricula can be structured around a core of problem solving activities (both on- and offline) and math investigations. Learners can then work through the strong direct instructional components of the curriculum to master the declarative knowledge and well-structured procedures needed to construct meaning.
Integration of math strands: algebra, geometry, data analysis, etc., taught each year. Connections among math strands are explored.	PLATO curricula are highly modular, and can be sequenced as the instructor desires. In addition, certain key concepts and skills, such as functions, are addressed in multiple levels to support a spiral structure.
Problem/situation-based approach: Students learn concepts and principles as they explore a real-world problem or situation. Students use a wide range of what they know to solve rich problems.	PLATO problem solving activities involve real-world scenarios of compelling interest to elementary, secondary and adult learners. The PSA's require integration of many math strands, as well as integration of math with other curriculum knowledge. Work can be done in collaborative or individual mode.
Function based approach: This goes hand-in-hand with the problem-based approach. Students observe real world functions early in the curricula and know the concept of function prior to learning formal notation and advanced concepts.	Functions concepts are introduced early in the Algebra I curriculum, and treated at multiple levels on into Algebra II.

NCTM Approach	PLATO Mathematics Curricula
Emphasis on Representation – math as language: Emphasis on many ways to represent problems and many ways to solve them using various representations (which leads to multiple solution paths and sometimes more than one acceptable answer).	Multiple representations are at the core of the PSA's, which typically support representations in graphical, equation, and matrix form. The elementary curriculum a also adds manipulables as a form of representation.
Emphasis on higher order thinking/process: Learners analyze, interpret, explain their reasoning. Learners generate algorithms.	Analysis and explanation of reasoning processes are at the core of the PSA's throughout the elementary and secondary math curricula, and in the Investigations activities in Algebra I and II.
New topics (and at lower levels): Data collection and analysis, statistics, probability, and discrete math topics are taught 6-8 and 9-12.	These topics are incorporated in the PSA's as well as selected tutorial activities throughout the elementary and secondary curricula.
Integration of information about the history of mathematics and its contributions.	In the new secondary mathematics architecture, found in Algebra I and II, the history of mathematics is a key element of the Investigations activities.
Technology integrated as tool to allow exploration of concepts/principles.	In the elementary curricula, the Toolbox is available for free exploration of concepts and principles. In the secondary PSA's, a Tool Bar provides similar access to appropriate free-play tools.

Instructional Design is the theory base which applies to all PLATO curricula. The instructional design standards of PLATO are based on a current cognitive learning theory (Anderson's ACT* model), and apply current best practice instructional strategy recommendations for teaching of each type of declarative and procedural knowledge. Further details are in Part 5 of this paper.

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Part

1

Introduction

From its origins nearly 40 years ago, the PLATO system has built the largest base of basic research on computer-based learning in the field. Beginning with research funded by the National Science Foundation and conducted at the University of Illinois and collaborating institutions, nearly 900 references on the PLATO system are listed in the ERIC educational research data base. PLATO *Technical Paper #1*(Foshay 1994) summarized meta-analyses of the effectiveness of computer-based instruction, and also summarized selected reports on PLATO courseware through 1993.

This paper reviews three bodies of research relevant to the current PLATO Learning system. First, we will describe the PLATO independent evaluation program and summarize effectiveness studies performed as part of the ongoing program. Full-length evaluation reports are available from the PLATO Learning web site, www.plato.com. Next, we will provide an overview of the theory base in instructional design of PLATO courseware. Finally, we will summarize the theory base of the PLATO curricula in reading and mathematics. For greater detail on each of these curricula and their theory base, refer to the PLATO *Technical Papers* on reading and mathematics ((Foshay, McEvoy et al. 2000; Quinn, Foshay et al. 2000; Quinn, Foshay et al. 2000) also available from the PLATO web site.

The PLATO system is unique in the industry for its grounding in theory, comprehensiveness, innovation and quality. All of the core curricular products in the PLATO system have been built internally by a curriculum development staff which has been in continuous operation since 1976, and has evolved its instructional design standards and methodologies to reflect the state of the art in theories of learning and instruction and the major curriculum fields. By the end of this year, over 70% of the courseware in the PLATO portfolio will have been built from scratch in the past five years, or will have received a major instructional upgrade and expansion. PLATO products regularly receive awards for quality from universities, education magazines, and trade associations. PLATO courseware has been cited in recent textbooks on eLearning and instructional design, and has been the subject of many papers and presentations at academic research conferences in the past five years. As a result, PLATO has developed an enviable reputation as an exemplar of the state of the art in instructional design, curriculum theory, and learning and instruction, with impressive evidence of effectiveness with elementary, secondary, post-secondary and adult learners.

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Quinn, B., W. R. Foshay, et al. (2000). Teaching Early Mathematics with PLATO Software: An overview of the new PLATO elementary mathematics curricula and how to use them. Bloomington, MN, PLATO Learning, Inc.: 58.

Part

2

Research on Effectiveness of PLATO Curricula, 1994-2001

The current federal education legislation (the No Child Left Behind Act of 2002) has spurred renewed interest in research-based methods in education. The issue of defining just *what* constitutes adequate evidence of "research based" practice is problematical. Foshay and Quinn (Foshay and Quinn in press) argue that the issue has numerous complexities:

> A common perception is that experimental designs are "more rigorous" than quasi-experimental designs. As with all aspects of evaluation design, however, there are tradeoffs to be considered when choosing between experimental and quasi-experimental designs. Generally speaking, experimental designs yield findings that are easier to interpret and more credible for making causal conclusions. However, there are a number of limitations to experimental designs. They are more expensive to implement, since special arrangements are often required. They are often more intrusive requiring the participant, teachers, and others involved with the training activity to adjust their schedules to meet the evaluator's requirements. And there may be legal, policy, or natural constraints on the program being evaluated that make random assignment or other experimental conditions not possible.
>
> In addition to not being able to implement an experimental design, there are other times when quasi-experimental designs are more appropriate. The very fact that experiments are so intrusive may in and of itself change the situation so much that any results from an experimental study are not valid for describing what is likely to occur in the natural environment for the program being evaluated. As participants become aware that they are being studied they act differently, sometimes quite differently, from what might be observed in a more normal setting. In these cases it may be possible to identify existing measures that can be used, or even analyzed after the fact, using quasi-experimental designs.

Accordingly, PLATO Learning has adopted an ambitious and comprehensive program of evaluation research on effectiveness of its products; what we believe to be the largest such ongoing program in the industry. Its primary goal is documentation and dissemination of "best practices" in PLATO usage. This knowledge is an important benefit for our clients, because it gives them concrete models to adapt and use in their settings.

We are systematically pursuing a plan to gather data from a wide range of sites and applications of PLATO, in order to be able to say that:

- when PLATO is used in a given way
- with a given target population
- these are the results which have occurred, and
- these are the external test results which have been measured

This evaluation program applies these principles:

- Different ways of using PLATO will lead to different results. Therefore, it is important to study a variety of ways of using PLATO, so that we will be able to make recommendations for expected gains under different usage scenarios. These studies thus examine *all* of the effects of the program, and make no attempt to experimentally or statistically isolate the effects of PLATO alone. Instead, the studies emphasize a thorough description of how PLATO is used and the context of its use, as well as reporting achievement data. PLATO *Technical Paper #6, Instructional Models: Four Ways to Integrate PLATO Into the Curriculum* (Foshay 2000) distinguishes between three classes of use: *supplementary, complementary*, and *primary*. Most PLATO evaluations characterize the program studied according to these terms:

  Supplementary strategies use PLATO for review and reinforcement of what has already been taught by other means.

  Complementary strategies use PLATO to add new content to the curriculum, such as problem-based activities, enrichment, or remediation.

  Primary strategies use PLATO for initial teaching of parts of the curriculum.

- As discussed above, there are substantial limitations on the usefulness of experimental and even control group studies. Therefore, we use a mix of quasi-experimental (comparison group) and descriptive (case study) evaluation designs, and follow standard methodological recommendations appropriate to the design.

- All evaluations are performed by an independent evaluator. PLATO evaluations have been done by faculty members in instructional technology at major universities, by independent evaluation consultants with backgrounds in university and educational research laboratory settings, and by the clients' own evaluators.

- All evaluations include at least a post-test of achievement using a recognized non-PLATO test (most often a state competency test or other standardized test). Where possible, pre-test data also are obtained, and gain scores are reported along with their statistical significance. However, many educational programs do not have pretest data which precedes commencement of PLATO use closely enough to be of use in an evaluation.

- One question that often arises when discussing mean differences between two groups is the size of that difference. A common measure for the difference between two group means is called effect size. Effect size is calculated by subtracting the smaller mean from the larger mean and then dividing the result by the average of the two standard deviations for the means. In educational research an effect size of .75 or greater is usually considered large, from .50 to .75 is moderately large, and from .25 to .50 is usually considered moderate to small. An effect size that is less than .25 standard deviations is usually considered too small to be educationally interesting. Where possible, PLATO evaluations report effect size.

- There is no straightforward relationship between patterns of PLATO use and achievement, because of complexities of placement, progress, and various learner variables. As a result, we report utilization patterns and correlations of module mastery and time on task with achievement as a means of describing the program, but do not attribute causal significance to them.

- There is no intent to "prove" that PLATO is (or is not) effective vs. classroom teaching or other media. Media comparison studies have been widely criticized in the professional literature as uninterpretable, and the same would be true with any such study done with PLATO. PLATO is best conceived of as a tool which can enhance learning environments, not replace them.

The studies summarized here have been completed over seven years in academic environments[1]. The full studies are available at www.plato.com, or on request. For each study, the summary reports the name of the site (if permission was obtained to use it), a description of the context, the type of instructional model, achievement data and other quantitative results, and effect size (if it was reported). This summary is followed by a brief description of the program, and of other effects observed. A summary of additional reports completed from 1980-1993 is available in PLATO *Technical Paper #1, Effectiveness of Computer-Based Training: An Annotated Bibliography of Reviews, 1980-1993 (Foshay 1994).*

[1] Additional studies on JTPA and workplace sites, and a variety of program reports with qualitative data, are also available upon request.

Summary of Independent Third-Party PLATO Evaluation Research Studies in Academic Contexts, 1993-2001

13 studies by *independent evaluators* are summarized here, representing *wide replication* of the PLATO system across a range of implementations, each with an *independent evaluation.* Most use *standardized and published tests* for achievement. They include:

- A variety of study types (1 *experiment*, 2 *comparison group*, 7 *pre/post-test* with gains reported, 1 *case study* with ending achievement reported)
- A range of levels, including *elementary, secondary, and post-secondary.*
- *Service populations* include *urban, suburban, and rural*, many with *underachieving, low-income and diverse populations.*
- A variety of program types, including *full implementations* in *primary* uses of PLATO (mostly self-paced, mastery model, individualized with instructor tutoring and coaching), and *partial implementations* in supplementary uses (for review and reinforcement of classroom instruction), often with a goal of standardized test remediation or preparation.
- *Implementations are fully described* in the complete evaluation reports. They are briefly described here.
- *Program sizes* ranging from 25-1,000 students
- Program durations from 4 weeks to 4 years with *sustained gains* across multiple program cycles.
- Program cycles of less than 30 hours to two semesters

Note that since these studies were completed, the PLATO secondary reading curriculum has been completely replaced, the mathematics curriculum has been expanded and upgraded, and all other major curricula are being upgraded, expanded or replaced in the near term. Future evaluations will include these new curricula.

We can make these general observations from the studies:

- The greatest gains are in programs using the primary instructional model for a semester or more (at least 30 hours of use). Effect sizes, where reported, were up to 1.5, or 2 standard deviations. This represents improvements of up to 60% on achievement of standards.
- Supplemental programs generally produce smaller gains, but one study reported gains of over 3 standard deviations. Effect sizes were most

commonly under .5, representing improvements of up to 30% on achievement of standards.

- Improved graduation rates result in credit recovery and dropout prevention programs. The most effective programs reported credit recovery success for every participant. Pass rates on state exit exams ranged up to 85% in English, and 100% in Math.

- In the primary instructional model, longer programs with more study of PLATO produce greater effects, with significant correlations of up to +.83. While the relationships between time on task with PLATO and achievement are complex, and isolation of the effects of PLATO is never a goal of these evaluations, the relationship does suggest positive effects of PLATO.

Houston Community College Mathematics Department Developmental Studies Mathematics 1,000 students in Fundamentals of Mathematics I • 46 students in the control group • 35 students in the experimental group Random assignment to the groups.	**Study Type:** Experimental Study **Context Type:** Developmental studies math program, urban 2-year community college **Program Duration:** Experimental group (PLATO) averaged 27 hours Control group (classroom) had 48 hours in class with required homework
Key Quantitative Results: • Mean score improvement for the experimental group was 7.8 vs. 5.2 for the control group • On pretest, experimental group scored a mean of 15.49 (s.d.=4.99); control group scored a mean of 14.91 (s.d.=4.12), so the groups were equivalent. • On post-test, the experimental group showed a 24.4% gain, and the control group showed a 14.4% gain. • In a regression test, a beta of 0.10 was attributed to the experimental group ($p<.001$) • Correlation of usage to gain was .27 ($p=.015$)	**Significance:** $p=0.015$ **Effect Size:** +.61 **Measure Used:** Pre/post test: *Arithmetic and Basic Skills* test of the Committee on Placement Examinations, The Placement Test Program of the Mathematical Association of America
Instructional Model: Experimental group self-paced, mastery model, with instructor tutoring. Control group used the same instructors in class, with comparable curriculum. Curriculum aligned to the TASP.	

<table>
<tr><td rowspan="3">Fair Park HS, Shreveport, LA

Secondary Math and English

138 Students preparing for graduation</td><td>Study Type:

Comparison study</td></tr>
<tr><td>Context Type:

High school test preparation program</td></tr>
<tr><td>Program Duration:

1 year</td></tr>
<tr><td rowspan="3">Key Quantitative Results:

• In Mathematics, 79% of PLATO students passed, vs. 51% non-PLATO students
• In English/Language Arts, 79% of PLATO students passed, vs. 67% non-PLATO students</td><td>Significance: N/A</td></tr>
<tr><td>Effect Size: N/A</td></tr>
<tr><td>Measure Used:

Louisiana Education Assessment Program (LEAP)</td></tr>
<tr><td colspan="2">Key Qualitative Results:

• Teachers rated PLATO very highly and recommended expansion of the program.

• Teachers reported students "loved it" and commented on self-paced review and advancement.</td></tr>
</table>

Lakeland HS, FL Secondary Math and Reading 31 students (Math) 29 students (Communication)	**Study Type:** Case Study with pre/post test gains **Context Type:** Remedial lab for students who failed the FHSCT. Suburban HS uses PLATO labs for skill remediation, SAT preparation, and specific skill development, at all levels. 46% free/reduced lunch, 24% African American, 6% Hispanic, 2.7% dropout rate. **Program Duration:**4 years (data for 2 years)
Key Quantitative Results: Year 2 results: • Fall-to-Spring gains in math averaged 40 points, for an exit mean of 717 points • Fall-to-Spring gains in English averaged 18 points, for an exit mean of 704 points. At the second retest, • In math, 100% of students passed. • In English, 85% of students passed.	**Significance:** $p<.001$ (math) $p<.001$ (communication) **Effect Size:** 1.40 (Math) 1.58 (English) **Measure Used:** Florida High School Comptetency Test (FHSCT) pre-/post- test
Instructional Model: Primary mastery model instruction with active teacher in "guide on the side"role **Instructor Ratings:** 29/34 questions rated 4 or 5 out of 5 **Learner Ratings:** 15/20 questions had means above 4/5. 5 had means above 3/5.	

Apache Junction, AZ Elementary Reading, Math, Language Arts 100 elementary students 75 middle school students	**Study Type:** Case study with pre/post gains **Context Type:** Grades K-8 (data from grades 1-4) Remedial reading, language arts & math Urban fringe/rural, with white, Hispanic, American Indian, Asian, Black students **Program Duration:** 4 week, 64 hour summer program
Key Quantitative Results: • Grade 3 reading: average gain of 27% • Grade 3 math: average gain of 25% • Grades 2 & 3 final scores in reading & math ranged from 80% - 90% • Grades 1 & 4 final scores in reading & math ranged from 63% - 90%	**Significance:** Correlation between PLATO use and achievement significant at $p<.001$ Gains significant at $p<.001$ **Effect Size:** Reading: +2.16 s.d[2] Math: +3.13 s.d. **Measure Used:** Locally developed reading, language arts & math tests; pre- and post test data available for 3rd grade.
Instructional Model: Supplemental model; 25 minutes/day average use, average of 10-35 activities mastered **Qualitative Results**: **Instructor Mean Ratings (5 point scale):** Content 3.4 – 3.9 Instructional Design 2.8-4.0 Teacher experience 3.0-3.8 Student experience 2.6 – 3.3 PLATO Activities: 3.5 – 4.1 **Learner Ratings:** N/A	

[2] S.d.= standard deviation

Jobs for Youth – Boston **Madison Park Technical-Vocational HS, Boston, MA** Secondary reading and mathematics 185 students, 9th grade (Complete data for 77 in math, 47 in reading)	**Study Type:** Case study with pre/post gains **Context Type:** Urban underachieving students, many bilingual or non-English speakers (Spanish & Creole). Some learning disabilities, attention problems, problem homes **Program Duration:** 5 wk summer remedial program for the lowest scoring students in the lowest-scoring school in the state.
Key Quantitative Results: • Positive correlation between # Modules mastered and math post-test (r=.37, p<.05) • Math: average gain of 19 points on BPS math • Positive correlation between hours of PLATO use and reading gain (r=.38, p<.05) • Reading: average gain of 266 Lexiles	**Significance:** N/A **Effect Size:** Math: +1 s.d. Reading: +2 s.d. **Measure Used:** Pre/post-tests : Boston Public Schools Math (BPS) and Scholastic Reading Inventory (SRI)

Instructional Model:
Supplementary use, 40-50 min of PLATO, 4 days/week, in 4 hour block of math and/or reading instruction. Average total of 9-12 hours on PLATO.

Key Qualitative Results:

- PLATO was well liked by teachers & students.
- Learning curve and hardware issues
- Assessments long

Similarity of items in practice & tests (an advantage) may discourage use by teachers concerned with boredom

Instructor Ratings:
Mean ratings on all items 4 – 4.75/5, except training, 2.75.

Learner Ratings:
Mean ratings on all items above 3.5, except "I feel I'm studying what I need to" 2.4

Western Harnett HS, Lillington, NC	Study Type: Case study with pre/post gains
Secondary Math & Reading 25 students who failed the state competency test in November	**Context Type:** Rural HS with high military/transient population. Remedial program for students who failed the state competency test.
	Program Duration: 1 semester
Key Quantitative Results: • 60% of math students passed • 43% of reading students passed • Mean grade level gain of 1.68 in math • Mean grade level gain of 2.87 in reading	**Significance:** N/A
	Effect Size: N/A
	Measure Used: North Carolina Competency Test pre/post test

Instructional Model:
Primary instruction, individualized placement & self paced, with active instructor tutoring and coaching, and peer tutoring. In a 4 course/4 block per day schedule, learners used PLATO 2-3 blocks per week, from February through the end of the school year.

Key Qualitative Results:

- Instructor were positively impressed with PLATO and expanded its use to other applications.

- Peer tutors positive about PLATO.

Learner Ratings:

Peer tutors rated all questions with a mean of 4 or above.

R.L. Turner HS, Carrollton, TX Secondary Math 120 at-risk 10th grade students 144 11th & 12th grade students who failed the TAAS	**Study Type:** Comparison Study with pre/post gains **Context Type:** Diverse HS with 56% minorities, 38% Hispanic, 8% African American, 40% free/reduced lunch. Program targeted at risk 9th graders, and 10th – 11th graders who failed the TAAS. **Program Duration:** 2 years (math)
Key Quantitative Results: • Pass rate in math improved from 69% before the program to 83% • 74% of high-risk 10th graders passed the math TAAS. • 87.5% of at-risk 11th & 12th graders (who previously failed the TAAS) passed a re-attempt of the TAAS. • Overall school average pass rate for TAAS was 83% vs. 86% statewide.	**Significance:** N/A **Effect Size:** N/A **Measure Used:** Texas Assessment of Academic Skills (TAAS) (pre- & post-test for 11th & 12th grade, post-test for 10th grade) TAAS practice test pre-test for 10th grade.

Instructional Model:
Primary instruction with active tutoring and counseling. Individualized prescription, self paced, mastery model. Pullout program, at least 1 hr/week PLATO use in 30 min. blocks.

Key Qualitative Results:
Faculty and principal were positive about PLATO and felt it contributed to program success.

<table>
<tr><td rowspan="3">Lawrence Central HS, Indianapolis, IN

Secondary Math and English (reading & writing)

406 students, 11th grade (complete data for 136 in Math, 97 in English)</td><td>Study Type: Case study with pre/post gains</td></tr>
<tr><td>Context Type:
Remedial program for students who failed the ISTEP.
Suburban HS with mix of affluent, upper middle-class, blue collar, military, and poor learners. 25% minority, 30% below grade level.</td></tr>
<tr><td>Program Duration: Two years</td></tr>
<tr><td rowspan="3">Key Quantitative Results:
After 1 semester of study (year 1):
In math, mean score increased by 26 points
In English, mean scores increased by 25 points
After 2 semesters of study (year 2):
In math, mean score increased by 36 points
In English, mean scores increased by 28 points
Of 406 students in the program, all but 74 passed by the end of year 2.
Success in the course (based on PLATO module mastery) was positively correlated with ISTEP score (r=.44, p<.001 for Fall, r=.332, p=.028 for Spring).</td><td>Significance: p.<.001</td></tr>
<tr><td>Effect Size: N/A</td></tr>
<tr><td>Measure Used:

Indiana State Testing for Educational Progress (ISTEP)</td></tr>
<tr><td colspan="2">Instructional Model:
Primary instruction with teacher actively coaching and tutoring. Individualized placement testing, prescription, self-paced, mastery model. Alternate 90 minute blocks in PLATO lab and in classroom.

Key Qualitative Results:
Math and English teachers very happy with PLATO
Both attributed student success to PLATO
Teachers commented on fewer discipline problems with PLATO
Teachers noted need for a nurturing, involved lab manager

Instructor Ratings:
All questions but 5 rated 3/5 or higher

Learner Ratings:
Mean response on all questions 2.5 or higher out of 5</td></tr>
</table>

<table>
<tr><td rowspan="3">Central Cabarrus HS, NC

Secondary reading, math, language arts

320 students (credit recovery)

13 students (test review)</td><td>Study Type: Case study with pre/post gains</td></tr>
<tr><td>Context Type: Credit Recovery + Test Review/ Preparation for students who failed NCCT.
Diverse student population, near Charlotte, NC</td></tr>
<tr><td>Program Duration: 2 years</td></tr>
<tr><td rowspan="3">Key Quantitative Results:

• Of 320 students who qualified for remediation, all have successfully recovered credit.
For 13 students in test review, a significant positive relationship between PLATO mastery and NCCT test scores:
• Math: r=.59 (Dec.-May 2000), r=.57 (May 2001).
• Reading: r=.831 (May 2001)
• Language Arts: r=.833 (May 2001)</td><td>Significance:
$p<.05$ on all correlations except Math May 2001, p=.055</td></tr>
<tr><td>Effect Size: N/A</td></tr>
<tr><td>Measure Used:
NCCT (North Carolina Competency Test

Pre & post-test</td></tr>
<tr><td colspan="2">Instructional Model:

Supplementary, self-paced, individualized prescription

Key Qualitative Results:

In interviews, teachers and administrators were positive about PLATO and believed it contributed to student improvement on the NCCT.

Instructor and Learner Ratings: N/A</td></tr>
</table>

<table>
<tr><td rowspan="3">Career Centers of the Columbus, Ohio Public Schools

4 centers, including one accredited high school, Ft. Hayes</td><td>Study Type:
Comparison Study with gain comparison</td></tr>
<tr><td>Context Type:
Citywide Vocational Career Centers</td></tr>
<tr><td>Program Duration: 2 Years</td></tr>
<tr><td rowspan="3">Key Quantitative Results:

• On the Locating Information test, 18% of learners gained one level, while 27% of (non-PLATO) learners statewide declined one Work Keys level

• On the Reading for Information test, 28% of learners gained one level, while 4% of (non-PLATO) learners statewide declined one Work Keys level.
• On the Applied Mathematics test, 55% of learners gained one level, while statewide only 14% of (non-PLATO) learners gained one Work Keys level.
• At Ft. Hayes, as many as 46% of learners progressed one Work Keys level on one of the three tests.
The pattern of gain was strongest for the Data Processing career track, which used only PLATO for core curricula:
• On Locating Information, 43% (year 1) and 47% (year 2) gained one Work Keys level. By contrast, another program which did not use PLATO showed a decline of 5% in year 2.
• Results for Reading for Information show gains up to 27% vs. a decline of 16% in a non-PLATO program.
• Results for Applied Mathematics show gains up to 44% vs. a decline of 36% by a non-PLATO program in year 2.</td><td>Significance: N/A</td></tr>
<tr><td>Effect Size: N/A</td></tr>
<tr><td>Measure Used:

ACT Work Keys</td></tr>
<tr><td colspan="2">Instructional Model: Supplemental & Primary

Key Qualitative Results: None. Preliminary study.</td></tr>
</table>

Labette Community College, Parsons, KS Adult/Workplace Reading and Writing 19 students in Basic Writing I 8 students in Basic Writing II	**Study Type:** Comparison Study **Context Type:** Rural community college with Title III grant to improve academics, especially reading and writing, and retention. **Program Duration:** 3 semesters
Key Quantitative Results: • Basic Writing I, with mandatory PLATO use, averaged gains of 56 points, with a pass rate of 74%. Basic Writing II, with optional PLATO use, averaged gains of 11 points, greater variance, and pass rate of 50%. • Basic Reading I, with mandatory PLATO use, averaged 46 points gain and pass rate gain of 46% (66% total pass rate).	**Significance:** N/A **Effect Size:** N/A **Measure Used:** Compass reading and writing test pre-/post-
Instructional Model: Primary instruction, self-paced mastery model with active instructor coaching	

Forest Grove HS, OR High Intensity Learning Lab (HILL) 208 Secondary Mathematics, 9th Grade • 117 PLATO users • 91 Non-PLATO users	**Study Type:** Comparison study **Context Type:** State test remediation in math Students who failed at least 2 parts of OSAT in grade 8 30% on free/reduced lunch, 20% Hispanic **Program Duration:** 1 year
Key Quantitative Results: • HILL students average score increased from 228 to 232. These gains were more than two times larger than non-PLATO students. • HILL students maintained a statewide rank on post-test of 41%ile, vs. a 9-point decline from 54%ile to 45%ile for non-PLATO/non-HILL students • A significant relationship (r=.19, p<.05) was identified between PLATO module mastery and post-test scores.	**Significance:** p<.001 **Effect Size:** .19 **Measure Used:** Oregon Statewide Assessment Test Math Test-retest

Instructional Model:
Primary: self-paced individualized mastery model study with teacher in "guide on the side" role. 45 minutes in lab during 90 minute block, every other day.

Key Qualitative Results:
PLATO users reported feeling more confident about doing well in school.
Learners found PLATO easy to use, and they tried hard to master the curriculum.
The FGHS principal and the HILL instructor believe PLATO contributed to positive results.

Instructor Ratings:
All questions rated 4 or higher, except "my students were scheduled to use PLATO for as much time as they needed." = 3.

Learner Ratings:
All questions rated 3 or higher, except "the computer makes me nervous" = 2.

<table>
<tr><td rowspan="4">Fairview Elementary School, Dayton, OH

Elementary Mathematics

88 students, 3rd-5th grade (mostly 4th grade).</td><td>Study Type:

Case study with pre/post measure of gain</td></tr>
<tr><td>Context Type:

Title I math class

55% of students qualify for free/reduced lunch.

84% Black, 15% White, 1% Hispanic & Asian students.

91% average attendance rate</td></tr>
<tr><td>Program Duration: 3 years</td></tr>
<tr></tr>
<tr><td rowspan="3">Key Quantitative Results:
On pre-test, 4% of students were rated as proficient. End-of-year tests showed 24% of students proficient.
This compares with a school-wide average of 12% proficient, and a district-wide average of 14% proficient.
81% of students gained. Average pre-test was 191 (range 125-227); average post-test was 201 (range 148-247).
Students at the lower and higher ends of math ability gained at about the same rate.</td><td>Significance: $p<.001$</td></tr>
<tr><td>Effect Size: 0.5 s.d.</td></tr>
<tr><td>Measure Used:

Ohio State Performance test: mathematics</td></tr>
<tr><td colspan="2">Instructional Model:

Pullout program, teacher introduction, students rotate between primary software use 30 min/period, and 30 min. small group/tutorial work with teacher.</td></tr>
</table>

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Foshay, W. R. (2000). Four Ways to Integrate PLATO into the Curriculum. Bloomington, MN, PLATO Learning, Inc.: 53.

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Part

3

Theory Base of the Reading Curricula

Each PLATO curriculum receives guidance on content and research on instruction from a National Advisory Panel of experts. The panels include nationally recognized researchers in curriculum and instruction in the relevant field, senior curriculum specialists from school districts and colleges, and PLATO Learning's own curriculum specialists and instructional design specialists. In addition, PLATO Learning draws on its ongoing analysis of curriculum standards in all states, Canada and the U.K., as well as the synthesis of standards done by the Mid-Central Regional Education Laboratory (McREL). The goal of this planning process is to develop a standards-based map of learning outcomes to be taught, and to identify research-based "best practices" in teaching and testing each part of the curriculum, especially in a computer-based environment.

Detailed overviews of each curriculum, including a more extensive discussion of its underlying research base, its learning outcomes and the features of the products are summarized in other PLATO Technical Papers[3]. For ease of reference, however, discussions of the theory base underlying these curricula are excerpted here. This Part discusses the reading curricula, and Part 4 discusses the mathematics curricula.

This review of reading research focuses on the instructional practices that have been demonstrated as being effective for beginning readers. These practices are the research base for PLATO reading curricula.

A key finding from current reading research is that there is no "one best way" to teach a particular reading skill or capacity. A variety of instructional methods and reading approaches have been shown to be effective, depending upon the

[3] Currently available are:

Foshay, W. R., E. McEvoy, et al. (2000). Teaching Reading with PLATO: An Overview of the New PLATO Reading Solution and How to Use It, rev. 1. Bloomington, MN, PLATO Learning, Inc.: 67.

, Quinn, B., W. R. Foshay, et al. (2000). Teaching Beginning Reading with PLATO Courseware: An Overview of the New PLATO Beginning Reading Solution and How to Use It. Bloomington, MN, PLATO Learning, Inc.: 45.

, Quinn, B., W. R. Foshay, et al. (2000). Teaching Early Mathematics with PLATO Software: An overview of the new PLATO elementary mathematics curricula and how to use them. Bloomington, MN, PLATO Learning, Inc.: 58.

instructional objective and student characteristics. An effective reading program will likely involve a mix of instructional approaches, including direct instruction on well-structured tasks and problem-solving activities utilizing more open assignments and methods. Individual interests and learning needs should be recognized in the reading instruction. A broader, more comprehensive review of these issues in the reading process can be found in the PLATO Technical Paper, *Teaching Reading with PLATO.*

While a range of instructional methods has proven successful in teaching beginning reading, three areas of instructional focus have proven especially effective in helping young, beginning readers learn to read.

- Alphabetic principles, including phonemic awareness and phonics instruction
- Fluency including reading with accuracy, speed, and expression
- Comprehension as promoted by vocabulary instruction, text comprehension instruction, and teacher preparation and comprehension strategies instruction

The third area, comprehension, is particularly important as readers of any age progress past initial decoding; comprehension skills develop throughout education, and thus it is as important to develop comprehension strategies at the secondary and post-secondary levels as it is at the elementary level. Consequently, it is a major objective of the PLATO secondary reading curricula.

We will discuss some of the instructional issues regarding each these three areas of curriculum focus, and relate them to the PLATO reading curricula.

Alphabetic Principles

Beginning readers with little prior print experience need explicit instruction in the alphabetic principles of reading: letter identification, phoneme recognition and discrimination, phonemic awareness and phonics skills. Two areas of alphabetic principles shown to be most important in teaching beginning readers are phonemic awareness and phonics.

Phonemic Awareness

Phonemic Awareness (PA) is a vital skill for young children to develop. PA means that a child understands that spoken words are made up of a sequence of sounds and that these sounds correspond to letters of the alphabet. Understanding the alphabetic principle and developing greater phonemic awareness is the first step in developing literacy.

The importance of PA has been well documented in the educational research (viz., Ball & Blachman, 1991; Adams, 1990; & Adams, Forman, Lundberg, & Beeler, 1998). For instance, PA has been identified as the single best predictor of a child's future reading ability and can account for as much as 50% of the variance in reading ability during the first 2 years of instruction (Share, Jorm, Maclean, & Matthews, 1984). Blachman (2000), Ehri (1979), Stahl and Murray (1994), and Wagner and Torgesen, (1987) also report a strong correlational relationship between PA and learning to read. Bradley and Bryant (1983, 1985) have provided evidence for a causal relationship between PA and reading ability as well. In a recent meta-analysis of PA, the National Reading Panel (2000) determined that the effect size of PA on reading instruction (for 52 different published studies that included control conditions) was significant (effect size of 0.53). The importance of PA is further underscored by research reporting that people who have not been taught to read or write have great difficulty performing PA tasks (Morais, Bertelson, Cary, & Alegria, 1987), and that poor PA is a strong predictor of reading difficulties in the teenage years (Bradley & Bryant, 1983). This has important implications for remedial reading at the secondary and adult levels, for the small proportion of readers at this level who have poor PA skills.

Phonemic awareness is taught both explicitly and implicitly in the PLATO elementary reading curricula. As suggested by research, PLATO *Beginning Reading's* explicit phonemic instruction involves the use of phoneme manipulation with printed text. The course makes extensive use of a variety of strategies to build phonemic awareness:

- Phoneme isolation, which require recognizing individual sounds in words. For example, 'Mark the words on the screen that start with the /s/ sound.'

- Phoneme identity, which requires recognizing the common sound in different words. For example, 'What is the sound that is the same in the names Bill, Brett, Becca, and Bob?' (/b/)

- Phoneme categorization, which requires recognizing the word with the odd sound in a sequence of three or four words, for example 'Which word does not have the /i/ sound of the letter y? fly, yell, try.' (yell)

In addition, the program provides extensive experiences with text of all kinds, especially with poetry and word games, to help build phonemic awareness. Using both direct and indirect methods the courses systematically builds across the grade levels a foundation of the most basic phonemic skills to harder and more complicated skills in later grades.

The curriculum makes repeated use of word families and rhyming segments to teach reading of new words. This is an example of an analogy phonics instructional strategy. Analogy phonics involves teaching students unfamiliar words by analogy to known words (e.g., recognizing that the rhyme segment of an unfamiliar word is identical to that of a familiar word, and then blending the known rhyme with the new word onset, such as reading *brick* by recognizing that -*ick* is contained in the known word *kick*, or reading *stump* by analogy to *jump*).

Phonics/Phonological Awareness

Phonological Awareness is a reader's sensitivity to the patterns of spoken language that recur and can be manipulated without respect to the meaning that the language patterns ordinarily convey (paraphrase taken from Snow, Burns, & Griffin, 1998, p. 111). Phonological awareness is often confused with phonemic awareness. Phonemic awareness refers to a child's understanding of the sounds of individual letters and simple blends. Phonological awareness is a more inclusive term that refers to a child's ability to decode representations of more complicated combinations of letters and learn spelling.

Research from several disciplines provides strong evidence for the importance of developing phonological skills in learning to read (Adams, 1990; Blachman, 1997; Rieben & Perfetti, 1991; Share 1995; Stanovich, 1992). How children perform on phonological awareness measures is a powerful predictor of future reading achievement (Bryant, Maclean, Bradley, & Crossland, 1990). It has also been found that children who lack this phonological insight are likely to be among the poorest readers (Blachman, Ball, Black, & Tangel, 1994). Catts (1991, 1993) found phonological measures and the naming of objects could predict 83 percent of the children's reading outcomes correctly. Finally, a reciprocal causal relationship between early phonological awareness and early literacy acquisition has been established in the reading research (Snow, Burns, & Griffin, 1998).

The National Reading Panel recently conducted a meta-analysis of studies that examined phonics instruction. The panel (NRP, 2000) reported that systematic phonics instruction, that is, the explicit teaching of a set of specific letter sounds and having children read text that provides practice in using these relations to decode words, contributed more to children's growth in reading than unsystematic phonics instruction or alternative treatments. There was no single systematic phonics program that outperformed the others.

The PLATO *Beginning Reading* curriculum is designed to supplement phonics instruction. It uses an analogy phonics instructional strategy, which makes repeated use of word families and rhyming segments to teach reading of new words. Analogy phonics involves teaching students unfamiliar words by analogy to known words (e.g., recognizing that the rhyme segment of an unfamiliar word is identical to that of a familiar word, and then blending the known rhyme with the new word onset, such as reading *brick* by recognizing that -*ick* is contained in the known word *kick*, or reading *stump* by analogy to *jump*).

Since research shows that phonics instruction is both less needed and less effective for remediation of adults, it is not a major emphasis of the PLATO secondary reading curriculum. However, the phonics needs of adults are addressed through a third-party phonics curriculum available from PLATO Learning.

Fluency

Recent education literature suggests that fluency is a critical element in skilled reading (NRP, 2000; Snow, Burns, Griffin, 1998). In order for learners to become adept readers they must become proficient in the mechanics of reading. Specifically, learners need to develop fast and automatic word recognition processes, rapidly use punctuation, and group words into meaningful units (NRP, 2000). Developing these skills reduces the cognitive load associated with decoding, freeing up resources for understanding the text (comprehension).

Fluency has been largely ignored in the classroom (Allington, 1983). Ignoring fluency has negative consequences. The National Assessment of Educational Progress conducted a large study on fluency achievement in U.S. schools (Pinnell et al., 1995) which concluded that 44% of students sampled were disfluent with grade-level materials. The study also reported a relationship between fluency level and reading comprehension.

In its recent meta-analysis examining the effectiveness of methods for teaching fluency, the NRP identified an instructional approach that promotes literacy—guided repeated oral reading practice.

For students to develop fluency with a range of texts, they need adequate practice time reading these texts. The amount of practice to develop automaticity in children has not been established, but an estimate for developing reading fluency in adult learners is about 100 hours of instruction and practice per grade level gained (Mikulecky and D'Adamo-Weinstein 1991). There is a likelihood that young students will require practice time in this same order of magnitude at least. Some of the ways students can receive enough practice may be through reading aloud to each other in small groups, reading at home to parents or siblings, recording their voice as they read, and by the use of interactive computer programs for reading practice.

Fluency building is a major objective of both the elementary and secondary PLATO reading curricula. It is supported in the curriculum by previewing a text through listening and by having the students read along with a recorded model reader. In addition, the interactive design of the courses allows students to reread a text several times to become more familiar with it. The amount of reading students do in the *Beginning Reading* and *Projects for the New World* courses provides extensive practice with feedback from the computer. This extensive practice is a key element to developing automaticity in reading, a key component in reading fluency and comprehension. Similarly, in *Vocabulary and Reading Comprehension* in the secondary curriculum, literally hundreds of hours of practice are provided, at graded difficulty levels and with short, medium and long passages of various expository and narrative types, with high interest value to secondary and adult readers.

Comprehension

Comprehension is a complex and necessary skill that readers of all ages and levels need to develop. The ultimate litmus test of a successful reader is whether they understand (comprehend) the text they are reading. Consequently, comprehension has been described as the "essence of reading" (Durkin, 1993 as cited by NRP 2000).. The National Reading Panel (NRP, 2000) identified three important areas of comprehension: vocabulary instruction, text comprehension instruction, and teacher preparation. These areas of comprehension and the panel's findings for each are briefly reviewed below.

Vocabulary

The NRP provides the following rationale for the importance of vocabulary instruction in teaching reading (p. 4-15).

> *As a learner begins to read, reading vocabulary encountered in texts is mapped onto the oral vocabulary the learner brings to the task. That is, the reader is taught to translate the (relatively) unfamiliar words in print into speech, with the expectation that the speech forms will be easier to comprehend. A benefit in understanding text by applying letter-sound correspondences to printed materials only comes about if the resultant oral representation is a known word in the learner's oral vocabulary. If the resultant oral vocabulary item is not in the learner's vocabulary, it will not be better understood than it was in print. Thus, vocabulary seems to occupy an important middle ground in learning to read.*

A review of the research literature indicates that vocabulary should be taught both explicitly and indirectly. Explicit instruction is highly effective for vocabulary learning (Tomeson & Aarnoutse, 1998; White, Graves, & Slater, 1990; Dole, Sloan, & Trathen, 1995; Rinalid, Sells, & McLaughlin, 1997). In addition, the more connections that can be made to a specific word, the better it seems to be learned. For example, there is empirical evidence indicating that making connections with other reading material or oral language in other contexts seems to have large effects.

PLATO curricula combine explicit and indirect vocabulary instruction. For example, the secondary *Vocabulary and Reading Comprehension* curriculum includes explicit pre-reading vocabulary instruction using the *Vocabulary Builder* tool, and teachers also can create their own vocabulary lessons with this tool. For indirect instruction, many curricula include glossaries with audio for difficult terms, and provide a full, age-appropriate, online dictionary which allows the learner to look up the definition of any word on the screen with a few mouse clicks.

Comprehension Instruction

The second area reviewed by the panel was text comprehension instruction. The NRP examined 203 articles that reported on the effectiveness of different comprehension instructional practices. The Panel's analyses identified sixteen categories of text comprehension instruction of which seven appear to have a solid scientific basis for concluding that these types of instruction improve comprehension in non-impaired readers. Some of these types of instruction are helpful when used alone, but many are more effective when used as part of a multiple-strategy method. The seven effective types of comprehension instruction are as follows:

1. Comprehension monitoring, wherein readers learn how to be aware of their understanding of the material;

2. Cooperative learning, where students learn reading strategies together;

3. Use of graphic and semantic organizers (including story maps), where readers make graphic representations of the material to assist comprehension;

4. Question answering, where readers answer questions posed by the teacher and receive immediate feedback;

5. Question generation, where readers ask themselves questions about various aspects of the story;

6. Story structure, where students are taught to use the structure of the story as a means of helping them recall story content in order to answer questions about what they have read; and

7. Summarization, where readers are taught to integrate ideas and generalize from the text information.

The most often used and scientifically based instructional practices involved teaching children how to ask questions when they read, how to monitor their comprehension, and how to provide summaries of text. Readers engaged in question generation ask themselves who, what, when, where, why, and how questions while reading. Readers engaged in comprehension monitoring keep track of their comprehension processes and take action when these processes break down (Wray, 1994). Readers engaged in summarizing identify the important elements of the text and unite those into a coherent whole (NRP, 2000).

Reading comprehension is one of the outstanding strengths of the *Beginning Reading* and *Projects for the Real World* curricula, the PLATO elementary reading curricula. Extensive comprehension practice, with exercises using explicit and inferential questioning, at multiple levels. The curricula provide extensive vocabulary development by direct instruction, hyper-linked definitions of key or unusual words and phrases, and extensive experience with words in the context of meaningful reading activities. This combination of explicit and indirect instruction is an effective mix for building vocabulary and knowledge about the real world children live in.

Comprehension instruction and practice is accomplished through many activities and projects that have children apply higher order thinking skills to understanding and using the information they read. The courses use the full range of comprehension strategies supported by research, including:

- Comprehension monitoring, where readers learn how to be aware of their understanding of the material;
- Cooperative learning, where students learn reading strategies together;
- Use of graphic and semantic organizers (including story maps), where readers make graphic representations of the material to assist comprehension;
- Question answering, where readers answer questions posed by the course and receive immediate feedback;
- Question generation, where readers ask themselves questions about various aspects of the story;
- Story structure, where students are taught to use the structure of the story as a means of helping them recall story content in order to answer questions about what they have read; and
- Summarization, where readers are taught to integrate ideas and generalize from the text information.

The PLATO secondary reading curriculum includes an even stronger, more sophisticated treatment of reading comprehension, in a spiral curriculum structure. Initial comprehension strategies are taught in *Essential Reading Skills 2*, which roughly parallels and thus reviews and reinforces the comprehension skills taught in the elementary curriculum. Next are the *Reading Strategies* series of curricula, which span grade levels 7-14. These curricula emphasize cognitive strategies for reading comprehension across a variety of text types and content areas. A key instructional strategy is based on the *think-aloud protocol* for modeling and practicing cognitive strategies, a state-of-the-art approach based directly on the research cited above. All of the PLATO reading curricula emphasize both referential comprehension and a wide range of inferential skills. The cognitive strategies taught mirror closely the strategies the NRP identified as best supported by research.

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Part

4

Theory Base of the Mathematics Curricula

This review of mathematics research focuses on the instructional practices that have been demonstrated as being effective for learning mathematics, and explains how they have been applied to the PLATO mathematics curricula. A key finding from this research is that there is no "one best way" to teach a particular math skill or capacity. A variety of instructional methods and teaching approaches have been shown to be effective, depending upon the instructional objective and learner characteristics. An effective math program will likely involve a mix of instructional approaches, including direct instruction on well-structured tasks and problem-solving activities utilizing more open assignments and methods. Individual interests and learning needs should be recognized in the math instruction. Therefore, the PLATO mathematics curricula use a mix of instructional approaches, and the software is designed to be used in a classroom as part of a larger mathematics curriculum, while still being robust and complete enough to be used by itself for self-instructional study.

The National Council of Teachers of Mathematics (NCTM) standards (1989, 2000) have been well received by national educational groups, the U.S. Department of Education, and the states as they reviewed or formulated new state standards, new benchmark tests, and new curriculum materials. The NCTM standards have led to less emphasis on skills for their own sake, more on deep understanding of important concepts that spiral through curricula and are interrelated. Even though a range of methods have proven successful in teaching mathematics, across these methods the following areas of instructional focus have proven especially effective in helping young learners to learn mathematics:

- Skill Modeling and Practice with Feedback
- Collaborative Learning
- Computation, Mental Math and Estimation
- Problem-Solving
- Active Learning with Real-World Connections
- Curriculum and Mathematics Connections

In this part, we will first discuss the influence of NCTM standards on the teaching of mathematics, and how PLATO has responded. Then, for each of these instructional foci will be discussed here, with an explanation of how PLATO curricula provide this focus.

Influence of Standards

Over the last decade, standards developed by NCTM have led to reforms of math curricula, textbooks, classroom practices, and state standards. In general, the NCTM standards argue for teaching math in a more holistic way. They promote teaching concepts, principles and skills in the context of real-world situations and teaching the connections among core concepts and principles.

The NCTM standards have been well received, but they are not without critics. On the one hand, the National Science Foundation has supported projects to implement the standards and to develop new textbooks and materials. The Department of Education has reviewed these and other math reform projects and labeled some of them "exemplary," and each state has looked to the NCTM standards when formulating their own graduation standards and benchmark tests. On the other hand, critics of the NCTM standards and the "exemplary" projects include some well-respected (and vocal) educators, mathematicians, and scientists. Many of these argue for teaching "math as math" – for retaining the kind of abstractions exemplified by a different reform, the "new math" the '60s. Critics also include some parents and teachers troubled by the shifts in the newer math textbooks away from "basic skills." They argue the reforms go too far, putting too much emphasis on the big picture at the expense of algorithmic skills, mental math, etc.

PLATO Learning believes the following trends in math instruction are likely to continue and grow in acceptance:

- In general, less emphasis on skills for their own sake, more on deep understanding of important concepts that spiral through curricula and are interrelated (fraction, proportion, ratio, scaling, patterns, functions, etc.). In other words, skills follow rather than lead.

- In general, more rich, multi-step problems. For some teachers, instruction is problem-driven, which allows the concepts and skills to be taught in context. For others, the rich problems come with or after formal instruction in concepts, procedures, and skills.

- In general, more emphasis on how math strands (algebra, geometry, measurement, probability and statistics, data collection and analysis, etc) are connected – more integration of the strands at each grade level.

- In algebra, a function-based approach rather than an equation-based and skills-focused approach.

- The addition of topics from these areas: pattern recognition, data collection and analysis, probability and statistics, functions, and discrete math. Topics from these areas are introduced earlier than in the past, so gaps in these areas are most apparent for grades 6-8.

- In the US, a shift in attention toward the bottom 25% of the class. This shift is largely driven by individual state standards (based on NCTM standards) and the mandated, high stakes tests that determine who passes and who graduates. State testing will accelerate changes in math instruction for the bottom 25% and add pressure to show good results quickly.

We believe these trends underlie the evolution of most state curriculum standards, and we are basing the evolution of our mathematics curricula on these principles. The table below summarizes key differences between the approach driven by NCTM standards and some traditional math teaching practices.

Table 1: Current Approach to Teaching Mathematics vs. What Preceded NCTM Reforms

NCTM Approach	Traditional Approach
Learner-based: The learner discovers and constructs meaning The learner encounters the core concepts and principles through investigation. (The teacher provides opportunities for investigation and facilitates.)	Teacher-based: The teacher/text lay out core concepts and principles. The learner practices and applies them.
Integration of math strands: algebra, geometry, data analysis, etc., taught each year. Connections among math strands are explored.	Separate strands: Math strands labeled and taught separately and in hierarchy: math fundamentals, algebra, geometry, trigonometry, probability, statistics.
Problem/situation-based approach: Students learn concepts and principles as they explore a real-world problem or situation. Students use a wide range of what they know to solve rich problems.	Modular, skills based: Concepts and Principles tend to be taught and tested separately with few chances to use them to solve a rich problem in context. Problems are constrained and tend to have one right answer.
Function based approach: This goes hand-in-hand with the problem-based approach. Students observe real world functions early in the curricula and know the concept of function prior to learning formal notation and advanced concepts.	Equation-based approach: Instruction about functions is delayed until advanced algebra. It is introduced with numbers and variables rather than a real-world situation. Real world applications of functions are in a separate module. Instruction is heavy with notation and terminology.
Emphasis on Representation – math as language: Emphasis on many ways to represent problems and many ways to solve them using various representations (which leads to multiple solution paths and sometimes more than one acceptable answer).	Table, graph, equation as ends unto themselves: The connections among graphs, tables, and equations are taught, but not emphasized and not generally connected to real situations.
Emphasis on higher order thinking/process: Learners analyze, interpret, explain their reasoning. Learners generate algorithms.	Emphasis on algorithms, answers: More emphasis on algorithms, the right answer, the outcome.
New topics (and at lower levels): Data collection and analysis, statistics, probability, and discrete math topics are taught 6-8 and 9-12.	Some coverage of probability and statistics, but not for middle school.
Integration of information about the history of mathematics and its contributions.	Little coverage.
Technology integrated as tool to allow exploration of concepts/principles.	Some resistance to technology.

The PLATO elementary curriculum applies these principles in both the tutorial curriculum and the interdisciplinary problem solving activities in *Projects for the Real World*. For example, in *Projects* there is extensive combination of math tasks and topics cross-strand, and problems provide compelling, authentic scenarios within which learners can connect what they have learned to what they know, as they solve problems. There is a tool-rich work environment, and instructors can use the open-ended environment to adapt the tasks within each project to the needs of their learners and their curriculum.

In the PLATO secondary math curricula, these changes are the principals which underlie both new product development and a major upgrade of the math curricula which is now under way. Instructionally, the upgrade stresses:

- A firm, cross-topic foundation of declarative knowledge
- Additional emphasis on authentic scenarios and problem solving
- Learning activities and explanations added and upgraded to enhance number sense
- Greatly expanded treatment of functions and other new topics at lower levels of the curriculum
- Additional emphasis on manipulatives and tools
- Additional emphasis on high-quality interactions and improved diagnostic feedback which directly addresses probable misconceptions
- Additions of the *Investigations* learning activities, which include math history, open-ended investigation with tools, and opportunities to relate math to personal experience.

In addition, the new architecture features a fresh, new interface and completely revised graphics, as well as revised text with controlled readability.

Now we will turn our attention to a review of research which discusses in more detail some of the instructional issues regarding the areas of instruction identified as key by NCTM and supporting research.

Skill Modeling and Practice with Feedback

The research basis for PLATO's approach to skill modeling with practice and feedback is summarized in Part 5's discussion of Tutorial modules. This mode of instruction is commonly used in PLATO curricula to teach declarative knowledge (facts, concepts and principles), and to teach well structured procedural knowledge. Heuristic principles for lesson structure are generally consistent with principles of direct instruction in the literature (refer to the table in Part 5). However, PLATO Learning has adapted and extended the principles according to current cognitive research, for each type of declarative knowledge as well as well-structured procedural knowledge.

Collaborative Learning

Collaborative learning is an important skill in its own right, and is a useful mode for teaching problem-solving (ill-structured procedural knowledge) and for reinforcing other knowledge types.

Cook (1993) noted that placing learners in small groups of two to six learners is an excellent instructional strategy for promoting reflective thought and for maximizing learner involvement in mathematics interaction. A number of researchers in recent years have demonstrated the high degree of learning possible when learners can collaborate in learning tasks and when they use their own knowledge as a foundation for school learning (Moll, 1989; Moll and Diaz, 1986; Palincsar and Brown, 1989; Palinscar, Ramson, and Derber, 1988/89; Brown, Palincsar, and Purcell, 1986).

Collaborative classrooms seem to have four general characteristics.

1. *Shared knowledge among teachers and learners.*

2. *Shared authority among teachers and learners.*

3. *Teachers as mediators.*

4. *Heterogeneous groupings of learners.*

The first two capture changing relationships between teachers and learners. The third characterizes teachers' new approaches to instruction. The fourth addresses the composition of a collaborative classroom.

In the PLATO curricula, and especially in mathematics, Problem Solving Activities (PSA's) have been created in the elementary and secondary curricula to support collaborative learning. They are open-ended problem-solving activities, based on real-world scenarios for the use of mathematics, in which learners work together to plan their strategy and execute it--and if necessary, try again, depending on the outcome. Thus, the PSA's are complementary to PLATO tutorials. The tutorials themselves, however, also may be used in collaborative mode, with pairs of learners working together.

Computation, Mental Math and Estimation

Computation, mental math and estimation are closely related topics. Reyes and Reyes (1990) provide a clear discussion of their inter-relationship.

Do you estimate? Of course you do. Everyone estimates. Research shows that estimation is used in real-world problem solving far more than exact computation. Furthermore, estimation relates to every important mathematics concept and skill developed in elementary school. It is a process that allows the user to form an estimate or to judge the reasonableness of a result. The NCTM's Curriculum and Evaluation Standards for School Mathematics (Standards, 1989) discusses both measurement estimation, for example,

About how high can you count in one minute?

About how many beans are in a 1kg bag?

Is more than 1/2 the area shaded?

and computational estimation, for example,

Have you lived 10,000 days?

I multiplied 48 by 0.27 on my calculator and got 129.6. Can that be right?

Everything is reduced 35 percent. About how much is saved on the stereo in figure 2?

These questions and the discussion of solutions offer many opportunities for developing number sense.

Estimation includes various interrelated concepts and skills, including mental computation, concept development and number sense. In fact, research suggests that number sense, mental computation, and estimation are often very difficult to separate. Further, the development of any one of these abilities often stimulates further growth in the others.

In the Standards, estimation is highlighted not as an end in itself but as a means for helping students "develop insights into concepts and procedures, flexibility in working with numbers and measurements, and an awareness of reasonable results" (p. 36). The study of estimation should be integrated with the study of concepts underlying whole numbers, fractions, decimals, and rational numbers so that these concepts can be constructed meaningfully by the learner. The exploration of a wide range of student-generated estimation strategies is recommended. The use of rounding to estimate is singled out for less attention in the Standards. Research and common sense clearly document that traditional rounding rules (rounding to the nearest ten, hundred, thousand, etc.) are often inappropriate and inefficient when estimating. Rather than follow rigid rules for estimating, students should be encouraged to use their knowledge about number to form estimates that are reasonable in the context of the problem. Often this strategy may call for "rounding" to numbers that are more compatible with the computation involved.

In grades K-4, the curriculum should include estimation so that students can-

- explore estimation strategies;
- recognize when an estimate is appropriate:
- determine the reasonableness of results;
- apply estimation in working with quantities, measurement, computation, and problem solving."

Even though these topics work so well together in a curricular sense, for the learner they are not at all the same in the way in which they are processed and remembered. Recent brain research has demonstrated that learning math facts is very different from applying mathematical reasoning. A recent MIT news release (Halbert, 1999), based on work reported in *Science* by French and MIT researchers, reported that:

> learning the multiplication table may be more akin to memorizing a laundry list than exercising mathematical skills. Meanwhile, learning to approximate how numbers relate to each other seems to be tied to intuition about space...
>
> Through separate studies involving behavioral experiments and brain-imaging techniques, the researchers found that a distinctly different part of the brain is used to come up with an exact sum, such as 54 plus 78, than to estimate which of two numbers is closer to the right answer; exact arithmetic uses a part of the brain usually active during verbal memory tasks... This part of the brain, while not a primary language area, is activated when subjects have to remember verbal material.
>
> Further, approximating seems to require a more spatial tool, such as a mental number line. This spatial tool, which some call *number sense*, may be the most important source of mathematical intuition, although this intuition probably also results from interplay between the two brain systems involved. The brain-imaging evidence... shows that approximate calculations take place in the brain's large-scale network involved in visual, spatial and analogical mental transformations... For years, mathematicians, including Einstein, have said that they rely more on mental signs and images than words.

Halbert wrote that not only were these math activities conducted in different locations, but also "the two kinds of math problems were instantaneously assigned by the brain to their respective areas, suggesting that the calculation itself, not just the decision to perform it, is completed by specific circuits depending on whether an exact or approximate result is required."

PLATO mathematics curricula include tutorial modules on mental math and estimation, and more are being added. In addition, open-ended investigations activities in selected tutorials often place the learner in situations requiring estimation and mental math, and the surrounding dialogs reinforce number sense. These skills also are an important part of the cognitive strategies needed in problem solving activities (PSA's) in both the elementary and secondary curricula. The PSA's are designed to support multiple solution strategies, and tools and occasions for estimation and mental math are built into the learning environment.

Problem-Solving

The NCTM standards suggest addressing richer, multi-step mathematics problems. One way this can be applied is to have instruction begin with a real world example rather than teaching concepts in the abstract. For example, graphing an equation is taught to show how real situations can be described by graphing data or graphing the equation that describes the data. Standards-based approaches to teaching mathematics build in more questions requiring explaining the processes and thinking behind the solution, or solutions. Math problem solving is designed to provide more modeling, investigating, explaining, and showing multiple solutions.

A recent study shows the benefit of approaching mathematics problem solving with a conceptual emphasis. A study of high and low achieving US classes (Nowell, Masini, and Quinn) found that teacher instructional practices produced measurable effects on learner TIMMS math achievement. In Grade 8 classes, teaching practices are related to higher or lower math achievement. Specifically, drilling learners on procedures and application of rules is associated with lower-achieving classes and focusing on understanding and explaining concepts is associated with higher-achieving classes. More teachers in higher-achieving classes ask learners to explain the reasoning behind an idea and write equations to represent relationships. While these results do not directly test the Standards for teaching developed by NCTM, they do show that teaching in a way compatible with the Standards is associated with higher math achievement.

In the PLATO mathematics curricula, problem solving activities (PSAs) using advanced architectures are included at both the elementary and secondary levels. The *Math Problem Solving* secondary curriculum, for example, uses real-world problem scenarios, open-ended problem solving and interactions in a tool-rich environment. Feedback is provided by means of an *Intelligent Coach* which monitors learner performance and provides a dialog on both problem solving strategy and tactics. Portfolio assessment is encouraged through a learner log which traces the learner's path through the problem, and allows comparison to an expert path.

In the elementary *Projects for the Real World,* real-world scenarios provide the framework for multidisciplinary problem solving. Learners use the tools of mathematics (as well as language arts, social studies, science, and other disciplines) to understand the problem environment and solve the problem.

Conceptual understanding is built in the tutorial modules, which are designed to "wrap around" or support the problem-solving activities. Both tutorials and PSA's can be used in collaborative learning contexts, which help build deep understanding.

Active Learning with Real-World Connections

Learning does not mean simply receiving and remembering a transmitted message; instead, "educational research offers compelling evidence that learners learn mathematics well only when they construct their own mathematical understanding" (Mathematical Sciences Education Board, 1990, p. 58). When educators begin to see learning as knowledge construction, they change their thinking about curriculum, instruction, and assessment, developing more powerful approaches to connecting thinking and mathematics and designing more mathematically significant instructional learning experiences (Cook, 1995).

Burns (1992) noted that not only is it important to consider the content of the mathematics curriculum, it's important to consider how learners *learn mathematics*. Learners need to learn mathematical concepts (declarative knowledge) and to see relationships among these concepts (knowledge structures). Because mathematics concepts are understood only as they relate to the overall framework of understanding held by each learner, children must construct these connections through an active process. Such learning experiences are:

- *Hands-on*, involving learners in really doing mathematics - experimenting first-hand with physical objects in the environment (manipulatives) and having concrete experience before learning abstract mathematical concepts

- *Minds-on*, focusing on the core concepts and critical thinking processes needed for learners to create and re-create mathematical concepts and relationships in their own minds

- *Authentic*, allowing learners to explore, discover, discuss, and meaningfully construct mathematical concepts and relationships in contexts that involve real-world problems and projects that are relevant and interesting to the learner.

This philosophy has been applied extensively in the PLATO mathematics curricula:

- *Hands-on* experience with mathematics is a feature of the new mathematics tutorial architecture, and in PLATO PSA's. Both provide manipulatives and powerful tools in scaffolded applications as well as for free-play use.

- *Minds-on* dialog is encouraged throughout in meaningful questioning and feedback which addresses misconceptions and stimulates deep understanding. The *Investigations* section of the new tutorial mathematics architecture, and the collaborative learning interactions encouraged in PSA's further stimulate reflection. In the secondary PSA's, dialogs with an *Intelligent Coach* apply intelligent tutoring technology to dialog with the learner at the strategy level as well as the tactical level.

- *Authentic* scenarios are used extensively to situate explanations, examples, practice and assessment. Example scenarios include planning a fishing trip, monitoring the progress of a species, managing growth of the stock in a greenhouse, and designing a playground.

Curriculum and Mathematics Integration

Research has verified the importance of building on learners' prior knowledge when helping them learn new concepts. This approach verifies not only the importance of articulating learners' math experiences from kindergarten through grade 12 but also the importance of aligning learners' math experiences with their other experiences both inside and outside school. Educators should keep in mind that the development of a child involves multiple settings--the home, the neighborhood, the school, and the workplace. People learn and grow in all of these settings. Learners of all ages construct meaning about themselves and their world out of personal experiences, including the influences of culture (Caine and Caine, 1991; Beane, 1995). Learning is enhanced when curriculum and instruction integrate learner experiences with the development of meaning. Iran-Nejad, McKeachie, and Berliner (1990) state, "The more meaningful, the more deeply or elaborately processed, the more situated in context, and the more rooted in cultural, background, cognitive, and personal knowledge an event is, the more readily it is understood, learned, and remembered" (p. 511).

NCTM gives the following pointers on the need for an articulate, coherent, and integrated math curriculum:

- A well-articulated curriculum challenges learners to learn increasingly more sophisticated mathematical ideas as they continue their studies.

- A mathematics curriculum should be well articulated across the grades.

- A mathematics curriculum should be coherent. Mathematics comprises different topical strands, such as algebra and geometry, but the strands are highly interconnected [and] displayed prominently in the curriculum and in instructional materials and lessons...Learners can see how the ideas build on, or connect with, other ideas, thus enabling them to develop new

> understandings and skills. An effective mathematics curriculum focuses on important mathematics—mathematics that will prepare learners for continued study and for solving problems in a variety of school, home, and work settings.

Note that *both* skills and applications such as problem solving are mentioned in this list. If learners are to become facile with mathematics, they need automaticity with skills and facility with mathematical reasoning.

The phrase "integration of mathematics instruction" may refer to either of two mathematics: (1) mathematics joined with other school subjects, such as math and social studies, and (2) different types of mathematics joined with each other, such as algebra and geometry. Both of these curricular combinations are legitimate ways of intertwining math so that it is better understood and appreciated.

In the PLATO mathematics curricula, both senses of "integration" have been systematically applied. Integration with other areas of study is accomplished through interdisciplinary problem solving activities (PSAs) in both elementary and secondary curricula. In addition, the new secondary math architecture includes interdisciplinary topics in the *Investigations* sections of the tutorials, in the form of background information on mathematics and open-ended invitations to explore the relationships between math and everyday life. Applied mathematics topics are found throughout the curriculum, even including curricula in topics such as statistical process control (SPC).

Integration of the multiple strands of mathematics is accomplished both within the PSAs and within the tutorial curricula. The PSAs integrate multiple strands of the math curriculum by providing tools and problems which can be solved using a combination of strategies (such as equations, graphing and matrices). Tutorial curricula are highly modular, and can easily be arranged in a multi-strand, spiral curriculum. Furthermore, in the new mathematics architecture, topics such as functions and matrix algebra are introduced early in the curriculum, and addressed again at higher levels.

The end result is unusually flexible, interdisciplinary, and comprehensive mathematics curricula, comprehensive from elementary number concepts through calculus, and rigorously aligned to state and national standards. The curricula strike a balance between the important emphases on problem solving and deep understanding, while giving adequate attention to computational skills. The curricula are designed for use in collaborative learning and conventional classrooms, yet are robust enough for self-instructional use in math labs, remedial and extended day or home settings.

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Part

5

Theory Base for PLATO's Instructional Design

Instructional Design is the field which seeks to apply research on learning, to derive prescriptive principles of instruction, and methods for designing learning environments which will apply those principles to reliably produce intended learning outcomes. PLATO's instructional design standards are continually updated to reflect current research on learning and instruction. In this section, we will first summarize the major influences of learning theory on PLATO's design standards. Then we will briefly summarize key standards which apply to each type of learning activity in the PLATO system.

Basis in Learning Theory

PLATO's learning theory is based on current cognitive learning research, in particular, the ACT* learning theory proposed by John Anderson (Anderson 1995). This model distinguishes between *declarative* and *procedural* knowledge. The following is adapted from (Foshay, Silber et al. 2002) and further explains the distinction:

- *Declarative* knowledge is knowing *that.*
- *Procedural* knowledge is knowing *how.*

These are examples of ***declarative knowledge***:

- Your phone number.
- Being able to tell the difference between a table and a tray.
- Stating that for a car engine to run, it must have air, fuel and electrical current for the ignition.

These are examples of ***procedural knowledge***:

- Driving to work in the morning by your standard route.
- Writing a paragraph with correct grammar and spelling.
- Adding a column of 2-digit numbers.
- Building a spreadsheet "from scratch" using a software package for spreadsheets, to apply a model of environmental carbon generation and consumption.

- Planning, rearching and writing a persuasive paper on environmental carbon policy.

- Planning a fishing trip's budget.

- Designing a copier that can't jam

The basic difference between the two types of knowledge is that declarative knowledge tells you *how the world* is, while procedural knowledge tells you *how to do things in the world.*

Educators who don't understand this distinction often confuse *knowing* and *doing*, and make a number of mistakes in designing training:

- they try to teach (and test) procedural knowledge using strategies which are suited for declarative knowledge;

- they teach declarative knowledge and stop, assuming that the procedural knowledge will naturally follow on its own;

- they try to teach the procedural knowledge without teaching the associated declarative knowledge.

Each of these practices results in ineffective learning and transfer.

Declarative and procedural knowledge each have a number of types. PLATO Learning's design standards emphasize that it is important to understand the different types so designers can recognize them when they plan instruction, and use instructional strategies which are appropriate to each type.

Types of Declarative Knowledge

Foshay, Silber, et.al. continue:

There are three types of declarative knowledge:

1. Facts, such as names, dates, definitions, formulas, vocabulary, and the like.

2. Concepts, such as groups or categories of things or ideas which go by the same name: table, car, love, causation, bigger, weight, mass and so on.

3. Principles, such as "if..then" or causal relationships which explain how the world works: gravitational attraction, commutativity, and so on.

Mental Models

It's important to know that the three types of declarative knowledge we've talked about so far (as well as procedural knowledge) fit together into structures. These structures are really *networks of principles* (with their supporting concepts and facts) and are part of **mental models**. For cognitive psychologists, mental models are the key to learning and using knowledge because:

- they tie together all the declarative knowledge in memory; they are the structures into which you organize information, put it into memory, retrieve it from memory when needed, and learn by expanding and restructuring existing structures.

- they provide the most meaningful application of declarative knowledge in isolation. As adults we rarely spout networks of facts (unless we are on *Jeopardy*), or run around finding new instances of concepts, but we do frequently try to explain how or why things happen or work.

- they form a bridge between declarative knowledge (knowledge about) and procedural knowledge (knowing how) – to do procedures (other than rote ones), you have to "know how the system works" – i.e., have a mental model of the system;

- the structure of the mental model is very different for expert performers and for novices. This indicates the importance of developing appropriate mental models if the learner is going to become a competent performer on the job.

Therefore, most would argue that for training of adults, the designer must not only teach isolated facts, concepts and principles, but must also help the learner create the appropriate mental models for optimum structuring of the information learned for storage, retrieval and application.

Educators commonly make a number of errors when teaching declarative knowledge:

- They teach all declarative knowledge as if it were fact, by requiring learners only to memorize and recall definitions

- They fail to ask learners to identify or construct novel examples (for concepts), or to predict and explain causal effects (for principles)

- They teach only the isolated facts, concepts and principles out of context, without providing a view of the "big picture" (mental model), and without helping learners to relate what they learn to their own mental models of prior knowledge.

Types of Procedural Knowledge

Foshay, Silber, et.al. continue:

Procedural knowledge is your ability to string together a series of mental and physical actions to achieve a goal. Procedural knowledge is used to solve problems and to *do* things in the world. The type of problem the procedural knowledge is used to solve leads to the description of the type of procedural knowledge. Problems vary along a continuum based on how well they are defined. (Anderson 1995; Jonassen 1997; Jonassen 2000)

- At the most precise end are *well structured* problems.
- At the far end are ill structured problems

A term you may sometimes hear for well-defined procedural knowledge is *rote procedure*. You may sometimes hear the term *cognitive strategy*, and *metacognitive strategy*. They are usually applied to moderately and ill structured problem solving.

Well Structured Problem-solving

We consider performing rote procedures to be well-structured problem-solving. All elements of the problem situation are known. Well-structured problems are usually performed simply by recalling procedures and performing them exactly as taught. It's not even necessary to understand *why* the procedure works. That means that in many situations it's optional to understand underlying *principles* that explain the *why* of a well-structured procedure. Examples of well-structured problem solving include calculating heating and air-conditioning requirements for a building, initial decoding in reading, or solving a long division problem.

Ill Structured Problem-Solving

In ill structured problems include most of the complex ones our learners meet in life. They are typically involved in *far transfer*, which is the goal of education. Examples of ill structured problems include almost any kind of design activity, be it writing, deriving and proving a formula, developing a public policy recommendation, or designing a new building. You've probably heard the old saw (a heuristic) that "defining a problem is most of solving it." That refers especially to ill structured problems. Ill structured problem solving is the best technical definition of "higher order thinking skills."

It should be clear that the continuum of procedural knowledge from well- to ill structured problems implies a significant range of knowledge and skill types. Furthermore, the role played by declarative knowledge, and especially by principles, varies considerably. Mastering any kind of procedural knowledge involves reorganizing the related declarative knowledge for the purpose of problem solving, and building and manipulating a mental model of the system being used, repaired, or designed.

Educators often make the error of teaching all problem solving skills as if they were well-structured. Sometimes, educators get so focused on teaching ill structured problem solving that they don't adequately teach the underlying declarative knowledge. While some learners can "figure out" the missing declarative knowledge, this instructional error usually leaves most learners with no choice but to attempt to learn the problem solving as a rote, well-structured procedure – much to the frustration of both the learner and the instructor. This is a common weakness of "constructivist" methodologies.

Note that this learning theory supercedes Bloom's *Taxonomy of the Cognitive Domain (Bloom 1974)*. While generations of teachers have used Bloom's *Taxonomy*, more recent theory development, reflected here, provides a more theoretically sound, better validated, and more prescriptively useful framework for instructional design.

PLATO Learning's Instructional Design Standards

PLATO's instructional designers are guided by a knowledge base of general instructional design standards. These are research summaries which are periodically updated to reflect current "best practice" in cognitive task analysis, instructional strategies, and computer-based instruction and assessment. The guidelines cover all forms of learning activities in the PLATO curricula, including tutorials, application/practice, simulation/problem solving, and testing. The guidelines describe instructional design standards for topics such as:

- Analysis and teaching of declarative knowledge, including facts, concepts and principles
- Analysis and teaching of mental models
- Analysis and teaching of well-structured and ill-structured problem solving
- Assessment of all forms of knowledge using online techniques
- Construction of highly interactive computer dialogs

- Tailoring instruction for the targeted learners
- Accessibility standards

A detailed explanation of these guidelines is beyond the scope of this paper, but the following figures summarize a number of the key points. Some design standards apply to all types of software, and some apply to specific learning activity types: tutorial, application/practice, informational/reference, tool, and assessment. Table 2 summarizes key general standards used by PLATO Learning (Gagne 1985; Sweller, van Merrienboer et al. 1998; Alessi and Trollip 2001).

Table 2: PLATO Curricula's General Design Standards

- *Organization, chunking and pacing* shall be clear and understandable to the learners.
- *Internal Consistency* of instructional components' content and knowledge type shall be maintained for all declarative and procedural knowledge types.
- *Learner Control* type and degree shall be appropriate for the learners and the way they will use the learning activity.
- *Flexibility* and modular structure shall allow learners and instructors to use the software as they want.
- *Interactivity and practice* shall be frequent, of the right knowledge type, and have feedback on wrong answers which addresses the reason for the error, or explains the principles involved.
- *Teacher's Role* shall be clear, and described in the instructor guide or help system).
- *Learner's Role* shall be suitable for the instructional model and the classroom.

In addition, there are design standards which apply to content or information, across all learning activities. These are summarized in Table 3.(Jonassen 1996; Reigeluth 1999; Reigeluth 1999)

Table 3: PLATO's Standards for Content/Information

- *Content* shall be clearly defined.
- Content shall be *complete and accurate* for the purpose and the learner.
- Content shall be *aligned* to the curriculum standards in both scope and knowledge type.
- A full range of positive and negative *examples and analogies* shall be included, which will be clear to the learners.
- *Layout* and *non-text cues* shall help learners understand the content's logical structure and direct their attention.
- *Reading level* shall be appropriate to the learners.
- *Graphics, visualization and multimedia* shall be used in ways which are instructionally needed and relevant, and which are appealing to the intended learners
- *Prior knowledge* assumptions shall correspond to the intended learners'
- Frame of reference, language and examples and imagery shall be *appropriate for the intended learners.*
- Adequate *accessibility* shall be assured through interface design and support of assistive devices
- Content shall be *free of bias* or stereotypes

Design Standards for Tutorial (Direct) Instruction

The most often used measures of learner achievement in the U.S. are scores on standardized tests of basic skills. Using this criterion as the desired learner outcome, one set of models, labeled direct or explicit instruction (Rosenshine 1986), has developed overwhelming research support in the past 25 years. Several principles of direct instruction, such as more teacher direction and learner-teacher interaction, provide the foundation for this approach. These methods of direct instruction or focused instruction have been used to teach mathematics and other subjects to a wide range of learners regardless of ethnicity, family background, or socioeconomic status. For example, both large scale and smaller scale experimental research comparing the outcomes of different forms of instruction show that:

1. Learners who are taught math using direct instruction methods generally outperform (both academically and with respect to self-esteem) learners taught with other forms of instruction.
2. The early gains of children who were taught some subjects with direct instruction are sustained in later grades.

Caldwell, Huitt, and French (Caldwell, Huitt et al. 1981) provide a direct instruction analysis from a transactional perspective. From this viewpoint, both the teacher and learner are active participants in the learning process, each with their respective responsibilities. At each event of instruction, the transactional perspective provides both a recommended teacher activity and a set of alternative learner activities. The most important deviation from the other models is that the transactional perspective emphasizes teacher/learner interaction at every event in the lesson. It is this principle of frequent, meaningful interaction that is at the heart of PLATO's instruction.

The following chart (adapted from Slavin 1997) provides a comparison of instructional events from several well-known direct instruction models that incorporate these principles. For comparison, we have added a column describing the PLATO tutorial module.

Table 4: Comparison of Direct Instructional Models

Good & Grouws (1979) (Missouri Mathematics Program)	Slavin (1994)	Gagne (1977); Gagne & Briggs (1979)[4]	Rosenshine (1995)	Hunter (1982) (Mastery Teaching)	PLATO Tutorials
1. Opening	1. State learning objective and orient learners to lesson	1. Gain and control attention; inform the learner of expected outcomes	1. Provide overview	1. Objectives; provide anticipatory set.	Motivation, confidence, objective, structure of content, structure of presentation
2. Review homework; mental computations; review prerequisites	2. Review prerequisites	2. Stimulate recall of relevant prerequisite capabilities	2. Review, checking previous day's work	2. Review	Link (Stimulate recall)
3. Development	3. Present new material	3. Present the stimuli inherent to the learning task; offer guidance for learning	3. Present new content & skills	3. Input & modeling	Presentation, Examples/ modeling, Relate (structure of content summary)
4. Assess learner comprehension	4. Conduct learning probes	4. Provide feedback	4. Initial learner practice, checking for understanding, feedback & correctives	4. Check understanding and guided practice	Practice, Feedback, Investigations
5. Seatwork	5. Provide independent practice		5. Independent practice	5. Independent practice	Application lessons
	6. Assess performance and provide feedback	5. Appraise performance	6. Frequent tests		Module test, prescription to review or go on
6. Homework; weekly and monthly reviews	7. Provide distributed practice and review	6. Make provisions for transferability; ensure retention	7. Homework; weekly and monthly reviews	6. Homework	Offline practice worksheets, PLATO Web Learning Network

PLATO tutorials form the self-instructional backbone of most major curricula. They are used for teaching declarative knowledge, mental models, and well-structured procedural knowledge. The tutorial format was the first activity type

[4] As discussed below, the PLATO tutorial strategy is an extension of the Gagne/Briggs model, but with independent practice added, and with a number of other enhancements based on current instructional theory.

developed on PLATO nearly 40 years ago. It has undergone substantial evolution in that time, reflecting advances in theory as well as improved software technologies. Table 5 summarizes key tutorial standards (Jonassen 1987; Fleming and Levie 1993; Reigeluth 1999; Alessi and Trollip 2001)

Table 5: PLATO's Standards for Tutorials

Tutorials lessons shall:

- Teach *well-defined objectives* which accurately describe the content and *Taxonomy* level of what is taught in each lesson.
- Start each lesson with an *orientation/overview* which signals *structure of content, structure of presentation,* and *establishes motivation and confidence.*
- Present information in *small and logically sequenced segments* which reflect the knowledge structure being taught.
- Size segments so they contain (for adolescents and adults) *up to 5-9 teaching points each,* in *up to 20-30 minutes* of study. For difficult content and for elementary-aged children, 3-5 teaching points and study times of 10-20 minutes are preferable.
- Provide *guidance* throughout the lesson to both the *knowledge structure* being learned and the *learning process* itself, through suggestions, symbolic cues, and feedback.
- Include frequent *meaningful questions or interactions* (not just navigation) for each teaching point, keyed to each teaching point and presentation segment, and appropriate to the knowledge type(s) being taught.
- Provide appropriate *diagnostic/explanatory feedback* on learner responses to the questions/interactions, especially for learner errors.
- *Model the right answer* if the learner gets "stuck" in an interaction.
- *Jump*, based on the learner's performance and goals, either automatically or by learner choice, to additional topics, examples or more practice in varied formats

Most tutorials are accompanied by additional application practice which reinforces the declarative and procedural knowledge taught in the tutorial, and extends the complexity, difficulty and contexts beyond those used in the tutorial. Standards for practice are summarized in Table 6.

Table 6: PLATO's Standards for Application Practice

Application Practice Lessons shall:

- Provide ample opportunities for practicing a particular skill (typically, at least 3 complete performances of the skill, across 15 or more questions/interactions)
- Provide practice in the desired direction of performance (from cue to response)
- Randomly sequence the elements practiced (except for well-structured procedures)
- Use relevant criteria to judge responses (often correctness and sometimes speed of response).
- Provide immediate and appropriate explanatory feedback based on the criteria for a correct answer ("No, that's not right because…").
- Provide progressive levels of difficulty, if appropriate to the content and purpose. Difficulty is controlled by varying cognitive complexity through factors such as number of cues, number of steps, and context.
- Contain multimedia elements as appropriate to the content.
- Keep learner interest and motivation in the program in a way which supports the intended learning outcome (rather than distracting from it).
- Provide meaningful interaction between user and the content included in the program (not just "click to continue" or interactions relevant only to the game).
- Use question formats similar to the Module Mastery Tests and state and national standards tests

Instructional Design Standards for Teaching Problem Solving

PLATO uses problem solving activities (PSA's), often called simulations, to teach ill-structured problem solving (a technical definition of *higher-order thinking skills).* PSA's use a number of formats, and are sometimes integrated with tutorials. They also are developed as stand-alone activities in some curricula. PSA's usually are designed to support either collaborative learning or solo use. Table 7 summarizes the key design standards for PSA's. (van Merrienboer 1997; Jonassen 2000)

Table 7: PLATO's Standards for Problem Solving Activities (PSA's) and Simulations:

Simulations and Problem Solving Activities shall:

- Provide imaginary experience of a real world or fantasy context which *reproduces those parts of reality needed for transfer* to other problems and contexts.
- Provide a *clear problem scenario* with clear goals.
- Provide all the necessary *rules of the game* and simulation-specific information needed to complete the task, without having to hunt for them.
- Include *all the key information and action steps* used in reality to solve similar problems (simplifying as necessary in early problems to provide *scaffolding*).
- Make *visible phenomena necessary to understanding*, even if they are not visible in reality.
- Allow the learner to make the *decisions for each key step* in solving the problem (allowing for scaffolding to skip or simplify steps when appropriate)
- Provide a plausible *range of decision/action options* for each key step, without unrealistic structure (except as needed to provide scaffolding in early experiences).
- Provide *realistic and plausible consequences* for learner responses.
- Provide necessary *tools and information* references needed to solve the problem.
- If teaching of problem solving is a goal, provide *coaching and feedback* on learners' actions which will stimulate reflection on strategy.
- Provide *variations* to allow replay after reflective thought.
- Enhance the process of transfer of learning by using *realistic scenarios*, and by *stimulating reflection* on basic principles and strategies

PLATO Learning's designers maintain a clear distinction between software which is designed to provide a complete learning environment, when framed and supported by an instructor (the three types discussed so far), and software designed to serve as one component of a learning experience created by the instructor. Two software types fall the in the latter category: informational software (which has presentations, but typically does not have the highly interactive response and feedback typical of tutorials), and tools (which are designed to be used for a purpose such as project building, experiments, reports and essays, and the like. In PLATO, both types of non-instructional software exist as stand-alone components, and when integrated with a problem solving activity. Standards for informational software are in Table 8, and standards for tools are in Table 9.

Instructional Design Standards for Information and Tools

Table 8: PLATO's Standards for Informational Software

Informational software shall:

- Include content at the right level of completeness and accuracy for the intended use and for the learners, including connections to primary source material as appropriate.
- Encourage critical assessment of information sources.
- Have graphics and multimedia features used to aid interpretation, and convey significant information and/or context, if there is a need
- Provide a search/exploratory environment which provides efficient *and* effective retrieval
- Be organized using a defined knowledge structure which is easily understood by the learner

These standards are based on (Jonassen 1982; Tufte 1998; Tufte 2000; Tufte 2001).

Table 9: PLATO's Standards for Tool Software
• Support whole, defined tasks as they are defined and described in the curriculum.
• Make appropriate assumptions about the learner's goals, skills and prior knowledge.
• Provide support for instructionally useful features such as storing work, tracking revisions, teacher and peer review/feedback.
• Scaffold and model tasks as appropriate
• Link together to share information among tools and among learners as appropriate.

Instructional Design Standards for Tests

PLATO Learning's assessment systems serve a number of purposes:

- *Placement* tests provide initial samples of skills taught, in order to make inferences about current achievement level and to exempt learners from study of skills they already have. They often use a dynamic "tailored testing" format, in which "testlets" are administered to learners depending on their performance on the test, so learners don't waste time by being tested on knowledge and skills far above or below their level.

- *Progress* tests check for mastery of the terminal objective(s) of each tutorial module, and are used to regulate progress through the PLATO curricula. These are often in the form of short (5-10 item) quizzes which accompany each tutorial.

- *Cumulative* tests are end-of-course tests which certify attainment of major milestones in the curriculum. They can be assembled on a custom basis so they test only assigned modules (through the Custom Assessment Test utility), or only assigned standards (through the PLATOLink system). They can be of any length.

- *Practice* tests emulate the form and content of state standards tests, such as math and essay writing. They prescribe relevant modules in the PLATO curricula.

Table 10 describes design standards which apply to PLATO tests(Osterlind 1998).

Table 10: PLATO's Standards for Tests

- All test items are defined by, and referenced to, specified learning objectives and curriculum standards.
- All tests shall be competency-based (rather than norm-referenced).
- Test items shall correspond in content and knowledge type to their objective.
- Test items shall be of formats which maximize reliability and validity for the required knowledge type being tested.
- Test items shall be edited using standard stylistic guidelines for each item type.
- Reading level of test items shall be no greater than for the corresponding courseware, and lower if possible.
- Where random item assignment is used, item pools shall be at least 3 times larger than the test length, or (in certain math questions) items will be generated using number generators.
- No judgement on mastery of individual objectives will be based on response to a single item. Depending on the test purpose, right answers on 3-8 items per objective are required.
- Domain sampling will be used for cumulative tests only.
- Progress tests will focus entirely or primarily on the terminal objective(s) for the accompanying lessons.
- Portfolio assessment techniques will be used for assessment of ill-structured problem solving.

The research base for these principles is derived from an extensive review of the instructional design literature, and the review is updated continuously. However, readers are referred to the following as core texts for instructional design principles upon which PLATO Learning's standards are based.

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A review of current research on workplace literacy programs reveals few programs reporting rigorous evaluations. Assessments are often limited to the completion of questionnaires, surveys of program participants, and anecdotal reports of effectiveness. Occasionally, a standardized reading test provides an indication of learner gains. Only a few evaluations provide follow-up data on the impact of programs on job performance, retention, or earning power. Trends among programs for which more rigorous evaluations have been performed are as follows: (1) effective programs require significant resources in terms of learner time on task; (2) effective private programs report learner cost figures more than double those of average public programs; and (3) effective programs integrate basic skills training with workplace technical training and usually involve counseling, on-the-job training linkage, and analysis of the basic skills needed on learner jobs. The eight-volume Job Training Partnership Act evaluation plan is the most thorough guideline for evaluating the effectiveness of preemployment literacy programs. Stufflebeam's Context, Input, Process, Product evaluation model has been modified by outside consultants for use with workplace literacy programs. This model uses interviews, document analysis, observations, and test data to determine program goals, sufficiency of resources, sufficiency of learning methods, and evidence of goal attainment. (14 references) (YLB)

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