Improvement in Instructional Testing

A Patent Disclosure

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1. Abstract

In this invention, we claim a computerized student test system (henceforth called the *scoring system*) in which a test or homework will be designed and printed through an instructor's PC platform, administered in paper form to the pupils, collected after the test, then scanned and presented to the instructor, also on said PC platform, in a manner that facilitates rapid and accurate grading of each test.

Several different forms of test question may be posed of the student, including, but not limited to, a typical multiple-choice bubble test.

A means (*entry panels* printed in the test) is also proposed by which a student may answer a question through a drawing, text, math equation, word or diagram completion, etc. which will later be presented to the instructor in a manner that facilitates manual scoring of the student's answer.

The scoring system will typically be provided as a software package, in which the minimum requirement is typically a reasonably modern Windows, Apple or Linux desktop computer, coupled with a scanner-printer. The scanner-printer may be an inexpensive laser flat-bed copier with a feeder. An alternative scanner-printer may be a larger networked office scanning copy machine, perhaps shared by an entire school or department.

This invention does *not* require any electronic systems or special hardware tools to be installed for the use of each student during a test. It is therefore eminently suitable for administering a test to a very large group of students, or in an environment in which the funds for individual computerized testing platforms are not available.

This invention does expect an instructor to possess some skills in preparation of a test through a common word processor, such as the Microsoft Word™ software tool, which most schools can acquire free or through a deep discount. A few extensions to Word can be easily mastered by an instructor, and are sufficient to use this invention's system to full advantage.

An alternative to teacher test writing may be the selection of tests or homework exercises from a battery available through a separate outside vendor, perhaps one affiliated with the textbooks used in the classroom, thus reducing or eliminating special skills required of (say) an elementary school teacher.

An *entry panel* is considered to be a rectangular area in the test in which the student is expected to write or draw something that would be beyond the capacity of known computer algorithms; these require human reading and evaluation. Grading the entry panels may be performed by the teacher, or by a team of graders working in parallel through networked computer stations, including graders operating in a different time zone somewhere else on earth.

There is clearly an opportunity to evaluate the graders with respect to establishing some uniformity in grading, as well as to evaluate the graders in terms of their grading speed. For critical tests, there is also an opportunity of having some questions examined and scored by more than one grader, as a way of establishing greater uniformity in grading and to evaluate grader performance. Such issues are supported

by the present invention, but not claimed, as they are beyond its scope and are typically supported by the art.

Human graders may choose to add *markups* to individual student panels, or to notice and flag special issues with respect to the individual student answers. For example, a short sentence written may be evaluated separately with respect to spelling, punctuation and grammar as well as intent.

An automated report for the teacher can be prepared that could be used to highlight issues common to most of the classroom students, as well as special issues for particular students in the classroom. For example, the report on a homework assignment in arithmetic might notice that Johnny is having trouble with certain entries in the multiplication table, while Susan doesn't seem to understand how to deal with carries in an addition problem.

Further automation could result in printing individual homework assignments tailored to each student's difficulty. If Johnny has trouble with certain multiplication table entries, he can be given additional drill work on those entries. If Susan has trouble with carries, some extra instruction in that followed by some specialized homework might be designed for her.

A system in which each homework exercise for each assignment and each student in a classroom would permit a sophisticated and automated analysis of the standing of each student. Teaching would suddenly become more specialized for each student, rather than generalized over the classroom. Every teacher aspires to reach such an ideal; few have the experience, memory, time and data analysis skills to attempt such a goal.

These automated approaches, directed toward more individual student-oriented instructional support, should result in a considerable improvement in student performance as a whole. Again, these benefits can flow from accurate, detailed data flowing from each student's performance on particular homework and test questions, carried in accessible electronic form in a computer database. How such a database might be used through specialized analysis software to achieve these results is beyond the scope of this invention.

2. Background of the Present Invention

Student testing (and homework assignment/grading/discussion) in a school environment has an ancient history. For a small class, the instructor may just administer an oral quiz separately to each student to establish the grades for each student. While ideal, the demands of today's class sizes and teaching loads dictate against much use of this practice.

In most schools, the instructor selects or designs and prints a single written test for the class, collects the test papers, grades them by hand, then enters the scores into a scorebook or database.

Recent improvements in the capacity, speed and (lower) costs of small office computers, and their peripheral devices, have made it much easier for an instructor to write and print a test on a PC connected to a printer, carrying the student names and scores in a spreadsheet or database.

Most instructors with access to a PC or Apple can write test or homework documents and supplementary teaching materials, print them and distribute them to their classroom. Publishers are increasingly providing homework and test material in printable form, available through a CDROM or the internet, with exercises tied to the textbook and often easily tailored or selected by a particular teacher. However, few teachers attempt to further register all student test or homework answers in a detailed manner, though many use a simple summary scoring system in a spreadsheet or grader tool to record and summarize each student's average performance.

Homework and test exercises completed on paper are typically graded with markups on that paper, an overall score assessment made by the instructor, recorded in a scorebook or spreadsheet, then the paper returned to the student. The best teachers keep mental notes on exercises that seem to trouble most of the students, then further drill the class on those topics.

Computer scanning technology has in recent years undergone great improvements in speed and accuracy, thanks to much higher computer speeds, large memory and disk capacities, together with dramatically lower costs of scanners and printers. It is now possible to purchase a high-performance computer equipped with a monochrome laser-based printer-scanner-FAX machine for less than $1000. Almost any school can now afford at least one such platform, and most schools can easily fund such a platform for each instructor or a small group of instructors.

Most schools have at least one industrial-scale high-speed office copying machine, with an automatic feeder, which is also capable of scanning documents into electronic form for transmission to a remote computer through a local network connection.

In fact, most modern copiers now scan a document in a separate unit, with a bit-mapped image sent to temporary disk storage in the machine. This can be sent electronically to the printer section of the machine or through the internet to a remote computer or printer. Similarly, a document (in a suitable format) sent to the copier through the internet can easily be printed. The separation of these two capabilities are particularly appropriate to the present invention.

Indeed, advances in scanning and character recognition have been anticipated in numerous patents related to the interpretation and machine recognition of paper forms. For example, Morris et al, 6,075,968 (June, 2000) teaches a generalized system that incorporates both computer and paper entries, with the paper entries computerized through an optical character recognition scheme, with distribution to a network of instructors in a school environment.

The Scantron™ System

A common automated test scoring and grading tool is the Scantron™ card reader [1]. Earlier commercial Scantron systems were leased or purchased and operated as a separate bureau in a school or school district, with its own management and maintenance staff. A teacher would ask the students to mark up a Scantron form (always in bubble form) in response to test questions, send the forms to the bureau, then receive a printed or diskette report on each student's overall score.

Recently, Scantron offers an expensive card reader and associated software to be connected to a PC through a USB or other port connection, thus making their system more accessible to the teachers and eliminating the ongoing costs of separate bureau [1].

Various form sizes and styles are in common use. A popular large form uses a preprinted 8 1/2 x 11" sheet with space for a name, a student ID or SSN, various other test identification, and numerous rows and columns for multiple-choice question entries. All of the Scantron systems are oriented toward multiple-choice test questions which can be answered correctly by choosing one of five possible bubbles each. Indeed, most mass tests, such as the college entrance examination (SAT) are designed with this restriction in mind.

Certain errors may creep into this process – the most common on the part of the student is checking the wrong group of bubbles. The test questions must be numbered, but unless the student takes some care in matching the question number to the bubble set (on the separate Scantron entry form), a few or many answers will be lost. The machine doesn't care what the question was, or whether the bubbles correctly correspond to the questions. It can only relate the student bubble checks to the teacher's master bubble sheet, and exhibit totals, averages and other information about the test.

Scantron has been generally accepted as providing accurate and automatically scoring of tests. However, the Scantron system, at present, is limited to multiple-choice test questions, typically up to five choices per question, plus a bubble scheme for entering a student name, SID number and other short pieces of data. It also requires that any multiple-choice test be on a separate printed page, and for the student to exercise care in locating the appropriate answer bubble on a separate answer page. Furthermore, when a Scantron

The limitations of multiple-choice tests are known to almost every instructor. For example, if a student merely checks the bubbles in a random manner, he/she will (on the average) receive a 20% score. For this reason, some instructors ask that *all* students be warped in such a manner that a random selection will result in 0% (on the average) and a perfect selection 100%.

Other limitations stem from students who examine all five choices, perhaps trying each one in an equation to be solved to see which one fits the best, rather than being asked to solve one or more equations for the unknowns. Choosing questions that tease out particularly abstract capabilities can be extraordinarily difficult, if not impossible.

See Hoffman [3] for a cogent review of these limitations.

Individual Student Computer Stations

Another alternative to paper-based testing is providing a separate computer platform for each student. This alternative is feasible with smaller, well-funded schools, and some that choose to set up a group of classrooms dedicated to test-taking.

Many instructional computer software systems require this, though perhaps with a limited, low-cost student terminal. Such systems look attractive on the sales room floor, but in fact have several drawbacks, *viz.*

1) the cost of providing and maintaining a separate station for each pupil may be prohibitive; this is a cost per station multiplied by the number of teaching classrooms in a school;
2) ensuring the isolation of each station during a critical test (should it be a networked PC) may be difficult
3) preparing what amounts to a simplified test format that suits the limitations of a small computer station (as opposed to a fully featured PC) can be very challenging.
4) teaching the pupils sufficient skills to use their computer station effectively, so that they may concentrate on the test at hand rather than on manipulating the computer station.
5) given that most schools are now required to provide special support to the handicapped, several computer stations would have to be especially equipped with the speaking program Jaws (for the visually impaired), or with special keyboard access tools, etc.

The cost of providing such an installation (1) is not yet within reach of most schools, even well-funded private academies. The one-time purchase price (starting as low as $150 per station for a very simple keyboard and four-line text screen) is a major consideration, but that is not the end of the cost of a computerized classroom. A maintenance employee or staff must be hired and paid out of scarce educational funds. A new computer system will typically have a useful half-life measured in a few years, given the rapid advances and obsolescence of hardware and software. A major system upgrade will require additional training and work from the maintenance staff. Any software, including the operating system, office products, *etc*. will typically require monthly or yearly upgrades. Computer systems will break down through bugs and/or hardware failure, rendering some stations useless, or even a whole school computer system useless through an uncontrolled virus, power surges or other causes.

A school must also consider the risk of having a test system go down through a virus, network failure, power failure, *etc*. just before or during a test period. While such a failure could also impact a teacher's PC, given tests printed in advance provides time to postpone the test, or to administer it in some alternative, more conventional way. The failure may also affect just one or two workstations, with others available to support the scoring system.

Regarding point (2), during a critical test the students must not only be physically isolated (requiring more space than usual for computer terminals), but also not be capable of sending and receiving messages to each other or to knowledgeable friends and family outside the classroom. Yet accessing the internet in certain restricted ways may well be within the scope of the test. Managing these distinctions will typically be beyond the capabilities of an average teacher, and could also challenge a skilled network administrator.

As an example of points (3) and (4), an instructor in geometry would surely want to ask each student to draw one or more geometric figures on a test. This would be impossible on a simple text-based entry station (3). On a more sophisticated computer (4), this would require each student to master a reasonable set of computer-based drawing skills. Getting this wrong, or getting bogged down in a test due an inability to make some drawing software "behave" will needlessly handicap an otherwise gifted student.

Also, many tests ask the student to provide an appropriate word in a sentence, or to complete some diagram. Nearly all students at all levels past basic writing can do this on a printed test form, but the corresponding computer version would require some training.

Point (5) is a cost and implementation issue, also one with legal implications. It is not clear to what extent a school district is legally required to meet the needs of all the handicapped students in their district. Depending on the nature of the handicap, the station may be reasonably standard or highly specialized. In any case, its installation and maintenance cost may well equal or exceed that of the rest of a fully equipped classroom.

Providing each student with an electronic station is therefore often either impossible due to lack of funding, or present serious limitations to the instructor in designing a test. The popular Scantron system is widely used, but only within the rather severe limitations of its multiple choice format.

Many instructors are therefore left with the sole alternative of administering a printed test, and grading it by hand, with little or no assistance from computer technology.

Avoiding Individual Student Computer Stations

Note that these costs and problems are obviated by *not* providing classroom-wide student platforms, instead just focusing on paperwork on the part of the student, and providing each teacher or teacher pool with a single PC system. A small school might have just one or two shared PC workstations attached to a printer-scanner, which all the teachers would share. Sharing of skills among the teachers in using the stations and its specialized software would also clearly take place. Maintenance would be minimized, perhaps through an inexpensive outside on-call service contract.

The present invention aims to avoid the high costs and problems associated with individual student computer platforms, yet provide many of the analysis, accuracy and efficiency benefits of modern computer technology, coupled with a flexible test or homework design environment.

3. General Description – Overview

See figure 1.

Note: the word "test" may equally be "homework", or "assignment" in this disclosure.

Test (or homework) preparation may begin with the instructor at a computer terminal 1 making use of the system, which incorporates a slightly expanded version of a popular word processor tool, such as the Microsoft Word™ or the Corel WordPerfect™ product 3. The test preparation view seen by the preparing instructor will typically look just like the final printed version, 2. Figure 2 (described below) illustrates the printed version of a typical test or homework page.

The test preparation view 2 may contain student information (not shown), bubble-style questions 20, two or bubble choices associated with their answer selections 12. It may also contain **entry** panels 13, with an embedded question or an external question. An entry panel may carry a diagram, completion sentence or be blank. See figure 2 and a discussion below of a sample test page form.

Test or homework preparation may alternatively be provided to the system in a downloaded format from an independent vendor, publisher, textbook author or other external means, not shown in figure 1. Thus a school teacher may elect to download a set of tests and homework exercises through the internet and may then modify, select, edit or otherwise adapt the vendor's suggested material.

The database

The prepared test material will find its way into a **database** 4, and perhaps also to a word processor file (not shown in figure 1). The database will typically be carried on the instructor's PC, but may also be carried in an external networked file server (not shown).

See figure 3 and a discussion below for more details on the preparation process, and a more detailed description of a suitable database.

Extensions to the word processor tool 3 are needed to meet these database needs; these fall within the domain of the present invention:

- create a database entry for each test page
- create database entries for each question and suggested answer
- create database entries for each entry panel image as it would be printed
- create database entries for each bubble position, entry size and entry position

Some or all of this data will be entered in the database upon completion of a test, typically comprising one or more pages of material. For example, bubble and entry positions on a page can only be fixed by the word processor after all preceding pages of text and other material have been formatted. These would most likely be dropped into the database just before a printing operation or before exiting from the word processor environment.

Under a simple regime, each printed test or homework is identical, except for a particular student name affixed along the top line in OCR characters.

Under a more student learning-centered regime, homework could be selected from a battery of homework exercises, especially designed to suit the needs of each individual student. We shall see that the scoring system prints each homework assignment for each student separately, by individually affixing the student name on each page. Scoring such tests by hand from the pages would be quite difficult, owing to the variety, but the present invention not only facilitates such specialization, but provides a reasonable solution to this manual scoring problem.

In addition, the database (more precisely described in a later section) is expected to carry information needed for test scanning and evaluation, *viz.*

- student names associated with a particular class
- student test scores

- markups by evaluators
- graders (or evaluators) used to evaluate student entry panels
- work history: evaluation progress, identification of graders, grading policy, grader performance, *etc*.

Student *names* in the database can be acquired by any of several different means, which are not further discussed in this invention:

- through downloading from a school registration computer network, or
- through manual entry by the instructor, or
- through a special bubble page prepared by each student, or
- through an entry form which a grader will read and use to enter each student name

Adjusting the student name lists to correct errors, add or drop students call for database menus which are well known in the art, and are outside the scope of this invention.

The student *test scores* will be filled in by the system through automatic bubble scoring or through manual grading operations, described later.

Markups by evaluators correspond to the comments and other marks that an instructor would typically write on a student test before returning the paper to the student. These are carried in electronic form and will later appear on the tests or test copies returned to the students, through the path 21.

The *graders*, or *evaluators* 10 will be identified and associated with each entry panel evaluated. There may be more than grader involved in evaluating a test, and more than one grader evaluating particular entry questions on the test. Also, although the evaluator will typically be the instructor him/herself, test evaluation could also be carried out by anyone equipped with a networked PC and this invention's system, anywhere in the world.

The *work history* refers to the state of evaluation of a test, *e.g.* viewing evaluation as a work in progress.

After Preparation

To continue the discussion of figure 1, after preparation of a test, all test pages will be printed through the system on a standard laser or dot matrix printer 5. This printer may be attached directly to the preparation work station 1, or controlled through a local network by any of several work stations, or be a central office printer/copying machine. In any case, the printer should be of reasonably high quality, *e.g.* 300 dots/inch, no wrinkles or tears, no missing lines, no extraneous lines or blotches, and no weak areas. Each page will later be scanned, and extraneous artifacts may not only interfere with a student's interpretation of the test, but degrade the later performance of scanning the page.

Each test page will be unique in that it will carry a line of OCR coding that identifies the test by number, the test page by name, and a unique student name – see Figure 2 for a sample form. Note that the printed test is *not* just a single test image copied multiple times. As noted above, a homework assignment may be tailored to the needs of individual students through specific actions of the teacher (not shown) or through some analysis of the detailed previous homework and test scores of the students, as collected in the database.

The tests will be separated by student name and distributed to the students for completion, 6, by the instructor.

A completed paper 7 will typically have certain bubbles checked 14, and some hand-written or hand-drawn entries 15.

In a test environment, of course, the instructor will proctor the students and gather the tests at the end of the test period.

For a homework assignment, the students may take their papers home or work on them in study hall, etc.

In any case, the students need to be cautioned to mark any bubbles carefully, to stay within the bounds of each entry panel. The completed pages should not be stapled, folded, etc., to facilitate scanning.

Collected papers may be arranged in any order, included mixed pages from any one test, then passed through an ordinary office scanner 8. We show a scanner with a feeder in figure 1, but an ordinary flatbed scanner may also serve the task, though it requires more time of the instructor.

A department or school copier-scanner may also be used, which can be requested to return all the scanned documents to the database through a TIF, PDF, or other file format. In this case, a department clerk or secretary might just feed them all through as collected by the instructors, in any order.

Scanning and Pattern Recognition

The scanned test now consists of a set of full-page images, to be processed by the scoring system software. Since several such tests may have been scanned and provided to the scoring system as a set of files or images within a single file, the tests, pages and students need to be separated and sorted electronically. This process is described in more detail below and in figure 4.

Pattern recognition algorithms 9, well known in the art, are applied to each full page image, for the purposes of:

- locating the fiducials,
- generating a location transform to map pixel locations in the full image into ideal pixels as captured in the database,
- recognizing an OCR line containing the test number, page number and student name,
- locating and scoring all bubble-based answers, and
- locating and copying all entry panels

The ideal fiducial locations and location of the OCR identification line are typically carried in a database section that is not shown in figure 1. The location transform will typically be kept in the database – its inversion will be used to print markup descriptions on the returned test, as needed.

Bubble-based answers on the printed form can be scored accurately by the system, and the scores entered into the database. Capture of bubble images appear to be pointless, although some school systems may desire to capture and keep whole images of student tests for archival or assessment purposes.

Entry panels are located through the transform, which will also be used to warp the captured image of the panel into ideal pixels. We note that neither printers nor copiers provide perfect renditions to and from paper, instead introduce small translational, rotational, and shearing errors in both printing and scanning.

Entry Panel Evaluation

If the test has one or more entry panels, there is a need for an evaluation phase 10. Given the great variety of penciled answer that a test may require of a student, including simple word answers written in what will likely be crude penmanship, or some diagram or drawing, no attempt is made to score these through pattern recognition. That situation may change as the technology improves; nothing in this invention should be construed as constraining the automatic scoring to simple bubble selection.

Entry panel evaluation is discussed in more detail later, and in figure 5.

Manual evaluation may of course be done directly on the printed tests, requiring no further work on the part of the instructor other than entering question scores into the scoring system. However, that would defeat one of the objectives of this invention, that of providing a more detailed and accurate student evaluation, and the possibility of individualized homework drill to suit particular student needs, along with a reduction in teaching labor.

For the purposes of this invention, manual evaluation of the entry panels will be performed by one or more human test evaluators 10, each working through a workstation and the captured database information. The persons will typically work through a PC platform as shown, which need not be the instructor's computer, nor a school department computer – it may be a remote platform located anywhere in the world.

An interesting social benefit of this scoring system may be to provide employment for third-world country persons with minimal computer training and skills in the test language, paid to grade tests for teachers somewhere else in the world. It is conceivable that a busy American public school teacher might prepare several homework and test assignments an hour before her classes in the morning, work with the students during the day, collect the student work, including homework, drop them all into the office scanner, have them scored overnight in the Middle East, Asia or India, then have the results ready for a printing markup the next morning for return to the students. Obviously, the overseas graders must be paid, but a significant difference in pay scales could mutually benefit the school district, its teachers and the graders.

The evaluator will see windows-based views 11, typically one per entry panel. This contains the entry question, if any, a suggested answer or answer pattern 17, the scanned entry panel 18 as extracted from the full page image, and an entry panel for the evaluator's score 19.

Any markup on a test should be placed within the entry panel as suggested, 16, and the scoring system will capture that in the database as yet another word processor-style image.

After Grading

After grading of a test is complete, the instructor may choose to reprint all tests, including markups, on blank paper through the printer 5. This operation requires that the scoring system superimpose the markups found in the database onto what would otherwise be an original printing of the test. The fiducials need not be printed, but the test number, test page and student name should again appear on the top line of each page.

Markups and scores may alternatively be printed on the original student paperwork. This obviously requires that the stack from a particular test or homework must be kept in order as they emerge from the scanner, with no pages lost or inserted, and placed correctly in the printer feed hopper of the printer.

Obviously, this is a risky maneuver, and will be compromised if either the scanner or the printer is subject to misfeeding errors.

We know at this writing of no printer equipped with a built-in scanner that can catch and interpret OCR coding and the fiducials in order to correctly select the appropriate test and page for printing markups from a database. Such a printer may emerge in the future -- the practice of this invention does not hinge upon the development of such a printer, but the scoring system may easily be adapted to such a use.

The instructor may then distribute the printed student work and engage in a discussion about questions that were consistently missed, as noticed by a summary report from the scoring system.

Summary reports may be augmented by analysis software that will suggest special drill homework for particular students with difficulties in particular topics. It is conceivable that notes to parents interested in aiding their children could also be issued from time to time through the system in paper or email form. These extensions are beyond the scope of this invention, but are clearly enabled by the detailed data collected through its processing.

4. A Typical Test Page

See figure 2.

A typical test or homework page as printed by the scoring system will contain a set of fiducials 30, 31, 32, 33, though they may not assume this exact form and cardinality shown. Additional fiducials along the side or bottom margins may be needed, depending on experimental findings of printer and scanner errors.

Along a top line will be found OCR printing with a test number and page number 34, and the student name 35. Should there be more than one student with the same name, the scoring system can easily detect that situation and provide an additional letter distinguishing those students.

These will be easily distributed if the instructor seats the pupils in the same order as they appear in the printed tests, e.g. alphabetical by first or last name. A stack of test papers may also easily be separated by test number. Adding a teacher name to the OCR would also assist in separation.

A multi-page test should not be stapled together, as no known scanner can automatically unstaple them.

The test entries may be arbitrary in form, for example:

- A geometric or diagrammatic question, with the question 36 separate from a partially completed entry panel 37, or a blank panel (not shown)
- A set of bubbles 38. Notice that the proximity of each bubble to its suggested answer reduces student errors due to mapping a lettered answer (a-b-c-d-e) to a separate bubble form. There is also no particular reason to constrain a bubble answer to a single choice – sometimes a choice of two or more bubbles is more correct than a single choice. (An automobile usually has 5 tires if you include the spare tire).
- The bubble set may be arranged in any convenient fashion, 39, though the preparation software will most likely choose an arrangement that minimizes overall paper area.
- An entry panel may contain a word entry or completion, typically used in English tests, 40
- Other varieties of entry answers, not shown, including writing or solving a math equation, a computer language component, a larger diagram, etc.

Each entry panel and bubble set will be associated with a suggested correct answer in the database, for the use of an evaluator; these are clearly hidden from the student.

5. Test Preparation and Printing

See figure 3, which is a combination of a flow chart of operations along with entity-relationship descriptions in appropriate sections of the database. *This is an illustrative database organization; any implementation may vary in detail. Most or all of these entities and relationships are within the art of database design, required by the present invention, but not so claimed.*

The instructor prepares a test or homework assignment through a computer station 41 using the scoring system's modified word processor 40. (These are shown in figure 1 as items 1 and 3, respectively).

A completed test is sent to a word processor file 43, and the database 42 *et al*, then printed through the database 42 and printer 44, producing the paper materials 45 to be distributed to the students. These components are shown in figure 1 as items 3, 4, 5 and 7, respectively.

Regarding the database organization 42, 46, 47 *et al*, the database consists (approximately) of a multiplicity of tables 42, containing other tables or links to other tables or sets of tables.

The annotation 1:n connecting two database table schema descriptions means that the first database contains a reference to a set of zero or more other database tables. The annotation n:1 means that the first database table contains a link to a single database table, the first consisting of a multiplicity of tables.

Each table 42 describes one test out of a multiplicity of tests carried by the database. Each table 42 contains a test number, a link to a multiplicity of page tables 46, a link to a miscellaneous table 50, and a link to a student table 49.

The misc table 50 carries miscellaneous generic information, *e.g.* the word processor file name, the instructor, the class, and perhaps more.

Each student table 49 carries information about one student. The scoring system needs a unique student (within a class), while the additional information will be of interest to the instructor, and may be carried in a separate database.

Each page table 46 contains a page number, a multiplicity of questions 47 (possibly no question), links to OCR information 52, and links to fiducial information 51. A pixel transform is also carried, which can map an ideal pixel position on the page into an actual position.

Each question 47 contains a test question, a correct answer, and either a bubble set or an entry fiducial shape.

Each bubble table 48 contains a single bubble answer (printed next to the bubble as a suggested answer) and a bubble position on the page, in ideal pixel coordinates.

Each entry panel table 53 contains an image of the (unmarked) entry panel, and its position. (The image typically carries the entry panel size).

Each OCR link in table 46 points to an OCR table 52 carrying an OCR style, position and size information. As with other positions and sizes, these are in ideal pixels – the actual positions and sizes as printed and later scanned may vary somewhat due to printer/scanner imprecision.

Each fiducial link in table 46 points to a fiducial table 51 carrying a fiducial shape, hot spot and set of positions.

6. Scanning and Pattern Recognition

See figure 4.

Papers as filled in by a student for a particular test 56 are passed through a scanner 57.

Each page yields a digital page image 58.

Recognition software is used to locate the fiducials 59 on the page. For this purpose, the database (shown in greater detail in figure 3) is first consulted for the fiducial shape and ideal positions on the page. The task here is to perform a local search for each of the fiducials within the full page image, a process that is well understood in the art, and that may be performed through a variety of means. The result, if the fiducials are found, will be the actual locations of the fiducial centers. (A fiducial "hot spot", as listed in table 51, figure 3, is a point located relative to the upper left corner of a fiducial bounding box, used as the "center position" of the fiducial).

Given the actual and ideal locations of the fiducials, an image transform 63 is computed. This will be carried in the database in the page table 46, figure 3. It should be capable of accurately mapping an ideal pixel position into an actual position. It should also be invertible, given that it will almost always be nearly a unitary transform. The computation of this transform is well understood in the art.

Using the coordinate transform 63, and the ideal position and sizes of the header OCR (test number, page number, student name, items 34 and 35 in figure 2), the OCR pixels within its frame can be transformed into ideal pixel coordinates.

A standard software recognition algorithm may then translate the OCR frame pixels into characters, item 65.

These in turn are easily parsed into the test number, page and student name. Operation 66 can then locate the test number, test page and student from the database through database items 67, 68, 69.

Given the test and test page, the database may be consulted to locate any bubble sets on the page, items 70 and 71. The links in figure 3 start with the test database 42, then a page table 46, the questions set 47, and a bubble set 48. Each bubble is examined, again with recognition software well known in the art, starting with the bubble center. Using bubble style and size information (not shown, but likely in the miscellaneous database table 50, figure 3), the software should be able to reliably determine whether the bubble has been penciled in by the student or not. Notice that the bubble center position must be mapped through the coordinate transform 63 for optimal results.

The bubble decision process may well result in one of three decisions: {filled, not filled, uncertain}. In the case of uncertainty, the scoring system may extract the bubble set image along with its questions, etc. to the manual scoring set for human evaluation. The number so sent should hopefully be a small percentage of all the bubble sets.

A bubble set represents one multiple choice question. The set of bubbles therefore can be represented by an array of bits, and that array of bits can be compared through various binary means with one or more correct answers. For example, a single choice from a multiple-choice question would have one bit set (binary 1) as the correct answer, with the other bubbles unset (binary 0). Other scoring possibilities include some combination of set and unset bits for a correct answer, or for partial credit.

In any case, the bubble set will be interpreted in terms of a score for that question, 71, and the score returned to the database.

For a manually scored panel entry, the entry location and size is determined through the transform 63 together with the ideal position as carried in table 53, figure 3. The entry image can therefore be extracted and warped into ideal pixels to form a pixel image 75, and that will be returned to the database as the "entry image", 76.

Some of the database tables and items entered are not shown in figure 3 for the sake of reducing the complexity, but the issues described therein are well known in the art of database design and management.

7. Manual evaluation, scoring and markups

See figure 5.

A *markup* is some mark attached to a student paper's answer as an aid to the student's understanding of the score, and as a means of indicating to the student that further study of that topic is suggested.

The simplest markup is a check or an X, indicating that the answer is satisfactory or unsatisfactory, respectively. It should be clear that the autoscored bubble answers could be so marked automatically, also that a numeric score can potentially be printed alongside or on top of the printed page returned to the student.

Other markups may be attached during the evaluation process, which works through database entries created after scanning and recognition of the test papers.

A *grader* is someone assigned to visually examine and score some or all of the entry panels.

Evaluation begins by registering a grader (85), assuming there is more than one person assigned to this task. This amounts to a login with a password by one or more persons authorized to score the student work (86).

The grader then selects a test, assuming there is more than one, 87.

Selecting a test provides an entré into the scoring database, releasing the test pages, entries and other data associated with that test, 88, 89.

The scoring system fetches the test entries, and may form an entry list for the grader, 90, 91. Alternatively, one entry at a time may be brought up for grading – this permits several persons to be working on the same test simultaneously.

The condition 92 succeeds if there is at least one more non-graded entry.

It is selected, 93, and the scoring system prepares a screen similar to 11 in figure 1.

The test question 98, correct answer 99, and student answer image 101 is brought up from the database and shown in a window (94-96), along with a score entry window 97.

A visual examination follows. The grader may enter a markup 16 through ordinary editing operations in the entry panel 18 (see figure 1).

The scoring system accepts the score and any markups (102, 103), and sends them back into the database (104, 105), which of course is able to associate them with a particular test and entry frame.

The entry is then marked "done" (106, 107).

The grader may choose to quit at this point, 108 (or before completing any of the above tasks, since a windows system permits an exit at any point).

Without quitting, control returns to 92 for another entry to grade.

This process is easily extended to several graders working in parallel in a manner well known in the art.

When all evaluations of a test are complete, the scoring system may prepare a test report for the instructor, which could include various measures of student performance, including the details of each student's performance on each question, summaries of each test question across the class, class performance as a whole, etc. These are all reporting issues outside the domain of this patent disclosure.

As discussed above regarding figure 1, the instructor may choose to print markups on the student test papers, or print a wholly new set of test papers, each with the markups attached. Having a color printer available would be an asset, as student paper markups are often done with a red pen to draw the student's attention to them. Markups in monochrome are possible, but easily missed by the student.

In any case, printing markups on the original student test papers requires passing all markups pixels through the inverse transform mappings for each page, and also advising the instructor to insert the test paper stack into the printer in exactly the same order as they were scanned. This precaution is clearly necessary since nearly all office printers lack the ability to first scan a page, even partially, perform some recognition operation (looking for the fiducials and OCR identification line) before printing the page.

Printing the complete test over again on fresh paper is an alternative strategy, although it obviously doubles the paper and ink cost, which will be a cost consideration for some schools.

8. Claims

1. We claim a computerized student test system (the *system*) in which a test will be designed and printed through an instructor's PC platform, administered in the usual way to the class in paper form, collected, then scanned and presented to the instructor, also on a PC platform, in a semi-automatic manner that facilitates rapid and accurate grading of each test, and thence printed afresh or overprinted in an automated manner to include grader markings, for return to the students.
2. We further claim that the system of claim 1 may be used to design, distribute, collect and score in a semi-automated manner student homework.
3. We further claim that the system of claim 1 may incorporate a flexible scheme of multiple-choice or true-false bubbles which can be automatically scored by the system.
4. We further claim that the system of claim 1 may print blank or partially prepared panels (*entry panels*) into a test, into which the student may draw any special image or write any message, or complete a diagram, sentence or other arbitrary figure, such entry panels to be later scored by presenting these scanned images to the instructor for manual review and grading through a windows operation.
5. We further claim that certain OCR (*optical character recognition*) methods [4] may be incorporated into said system of claim 1, for the recognition of student-drawn characters or other simple figures, for automated conversion into a sequence of such characters, and these may be automatically scored against one or more expected answers, or presented for manual viewing and scoring by the instructor.
6. We further claim that the system of claim 1 will provide a choice of test preparation software tools, the most important of which will be a common commercial word processor software tool adapted to the needs of this system. The said word processor tool will contain certain extensions that make it easy for the instructor to write comments, test questions, and expected test answers into an electronic document that will become the student's test papers.
7. We further claim that the system will contain a specially designed test scoring display system, which will typically present one scanned entry panel, along with its question and suggested answer, to the instructor on his/her computer monitor, for review and scoring. The questions to be graded will display the question, suggested correct answer, suggestions for variations on the answer, and a student answer shown serially through one question before moving to the next question.
8. We further claim that the grading system may accept various forms of markups of interest and value to the student, on any of the entry panels.
9. We further claim that the system of claim (7) may select student replies to a particular question in a randomized order in order to reduce grading bias.
10. We further claim that the system of claim (1) may accept sample sets of test questions from a publisher or other external source, for selection and/or modification for the instructor.

11. We further claim that the system of claim (1), based on the performance of particular students in tests and/or homework, may be given tailored homework designed to drill such students on particular topics, thus providing a high level of individuality of instruction.

Multiple Graders

12. We further claim that the manual test grading operations of claims 7 and 8 may be scored by several graders working in parallel through separate workstations connected by a network to the system's database.
13. We further claim that the manual scoring displays will continue until a grading response is received for each entry panel on all tests for all students, the system keeping track of which panels have not yet been scored.
14. We further claim that scored questions may be brought up for review or sampling, as a means of providing a form of quality inspection of the grading process.
15. We further claim that the system will report on the progress in grading a test, reporting on the level of completion of the process on any one test.
16. We further claim that each such grader among a multiplicity of graders may register with the system, such that each graded question may be associated with a particular grader.
17. We further claim that, given more than one grader, the system may provide some form of statistical evaluation of the differences between graders on the same questions, and some measure of the times spent on grading questions.
18. We further claim that, given more than one grader, they may communicate with each other and pass a troublesome student answer to others, perhaps a senior instructor, for evaluation.

9. References

[1] US patent 7,298,901 (2007): A scannable form with a numeric value block, a plurality of response control marks, response receiving rows, and a zone for a bar code, optical character recognition (OCR) spaces and/or intelligence character recognition (ICR) spaces. The scannable form may be scanned by two different devices.

This patent teaches a portable scanner for small Scantron cards, and a card definition. Each card is about the size of an IBM punched card, has two rows for a name entry (letters in square boxes), and about 90 rows for multiple-choice "bubble" answers. One row carries fiducials.

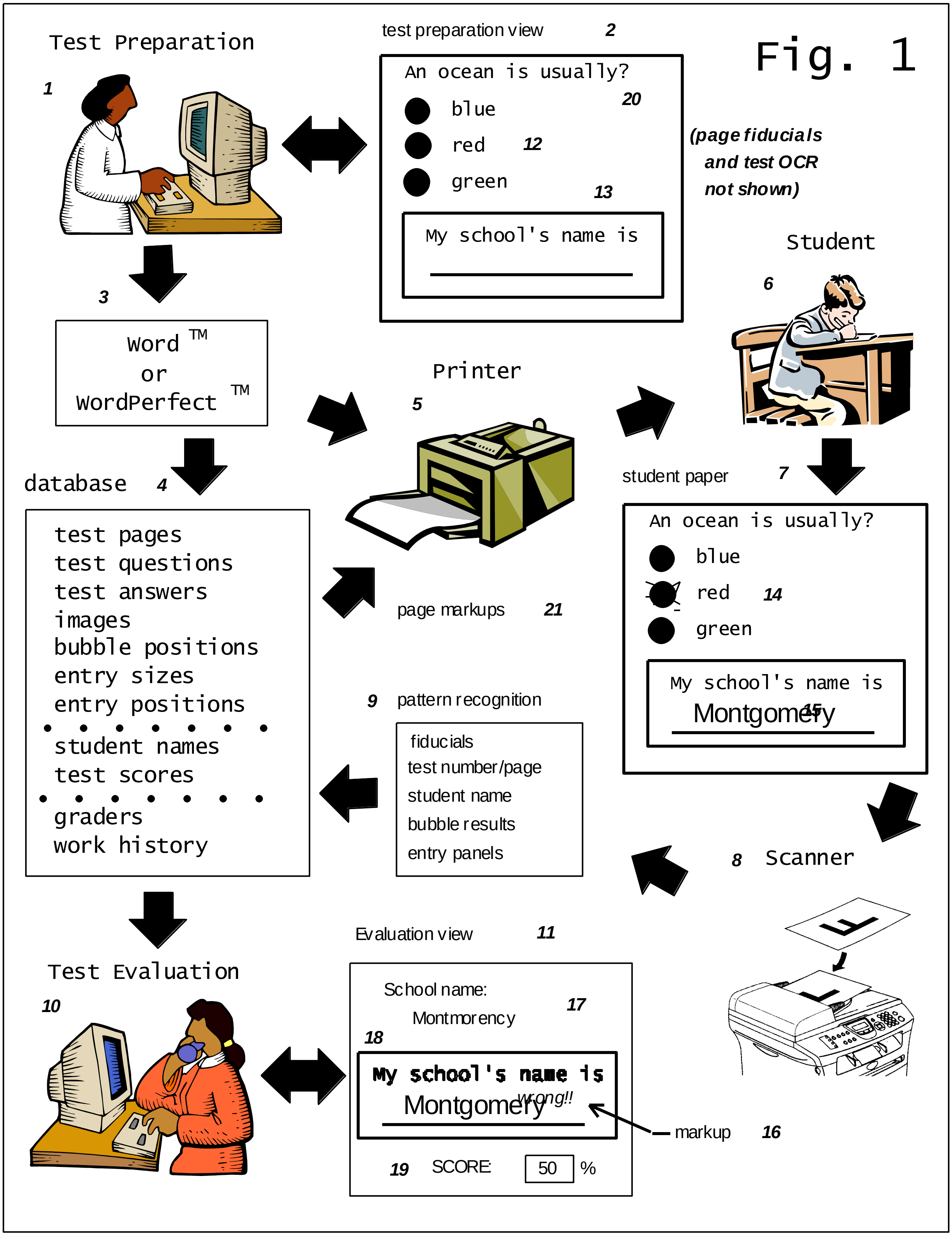
The scanner itself contains a column of photocells, and a motor drive that drives a card through the scanner. A card feeder is presumably part of the device. The device cannot read a student name, unless spelled out in a large table of bubbles – the instructor presumably does this, pushes through the card, gets a score on an LCD screen and enters it with the student name.

[2] Morris, *et a*l, US patent 6,075,968 (June, 2000): A system for educating learning disabled students includes a work station accessible by students and instructors for converting information between paper-written and computer character-recognized formats, whereby an instructor or a student can convert paper-written information such as assignments into a computer character-recognized format. The system further includes a plurality of student setups, each of which permit the exchange of computer character-recognized information with the work station. Each student setup presents computer character-recognized information to a student both audibly and visually in a synchronized manner to permit the student to acquire knowledge, understand assignments and produce work products in a computer character-recognized format that can be converted to a paper-written format at the work station for

submission to the instructor. A student support network provides the student with supplemental information and guidance as needed to obtain a quality education.

[4] There are some 5000+ US patents under the category of *optical character recognition,* which can be searched through the www.uspto.gov web site. Most of these involve first scanning a printed document into a bit-image computer format, then applying a pattern recognition algorithm designed to classify an arbitrary image into one of a very much smaller set of wanted characters, whether they be numeric, alphabetic, Chinese, Arabic, or some other common language element set.

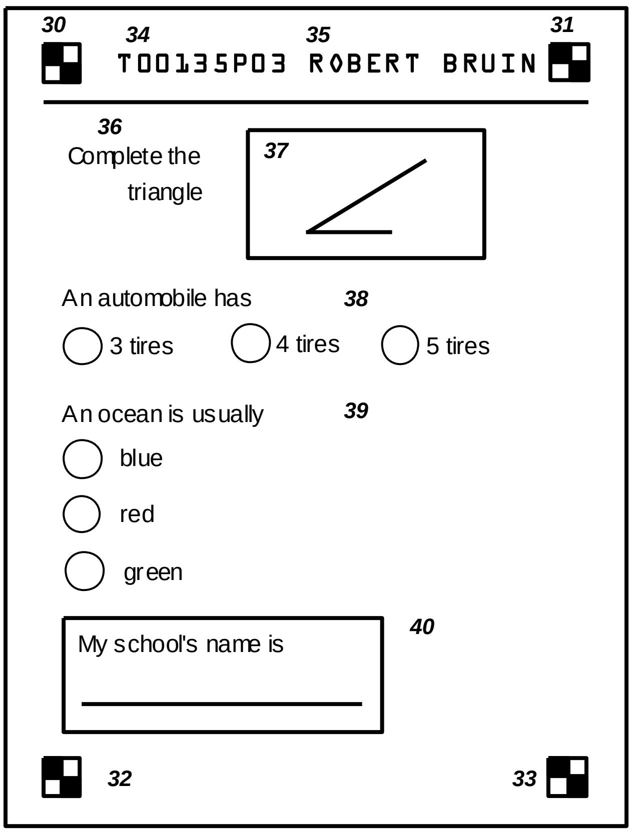
[3] Banesh Hoffman, *The Tyranny of Testing,* Jacques Barzun, 2003.



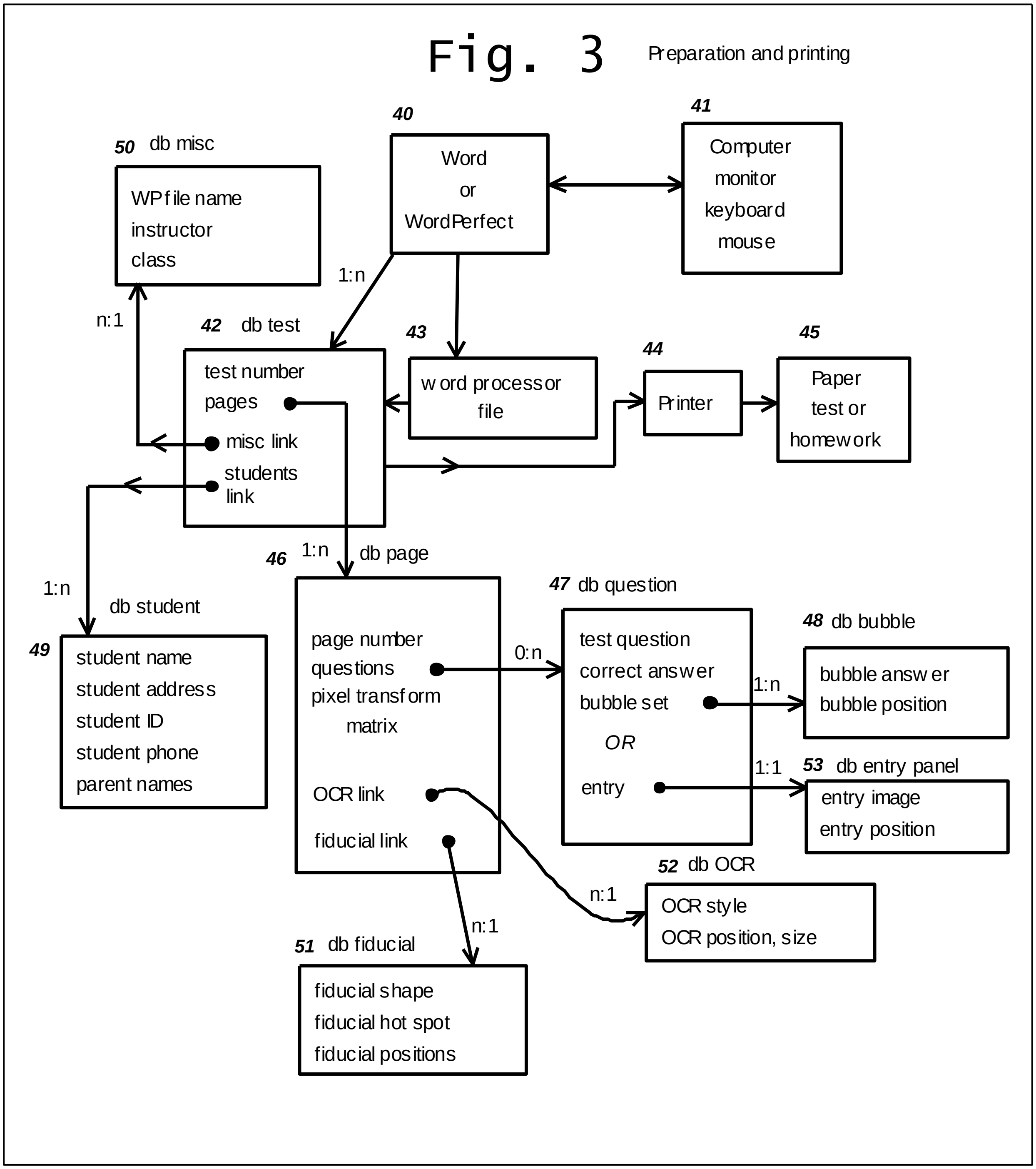
Witnessed and understood: ______________________ Date: ________

Fig. 2

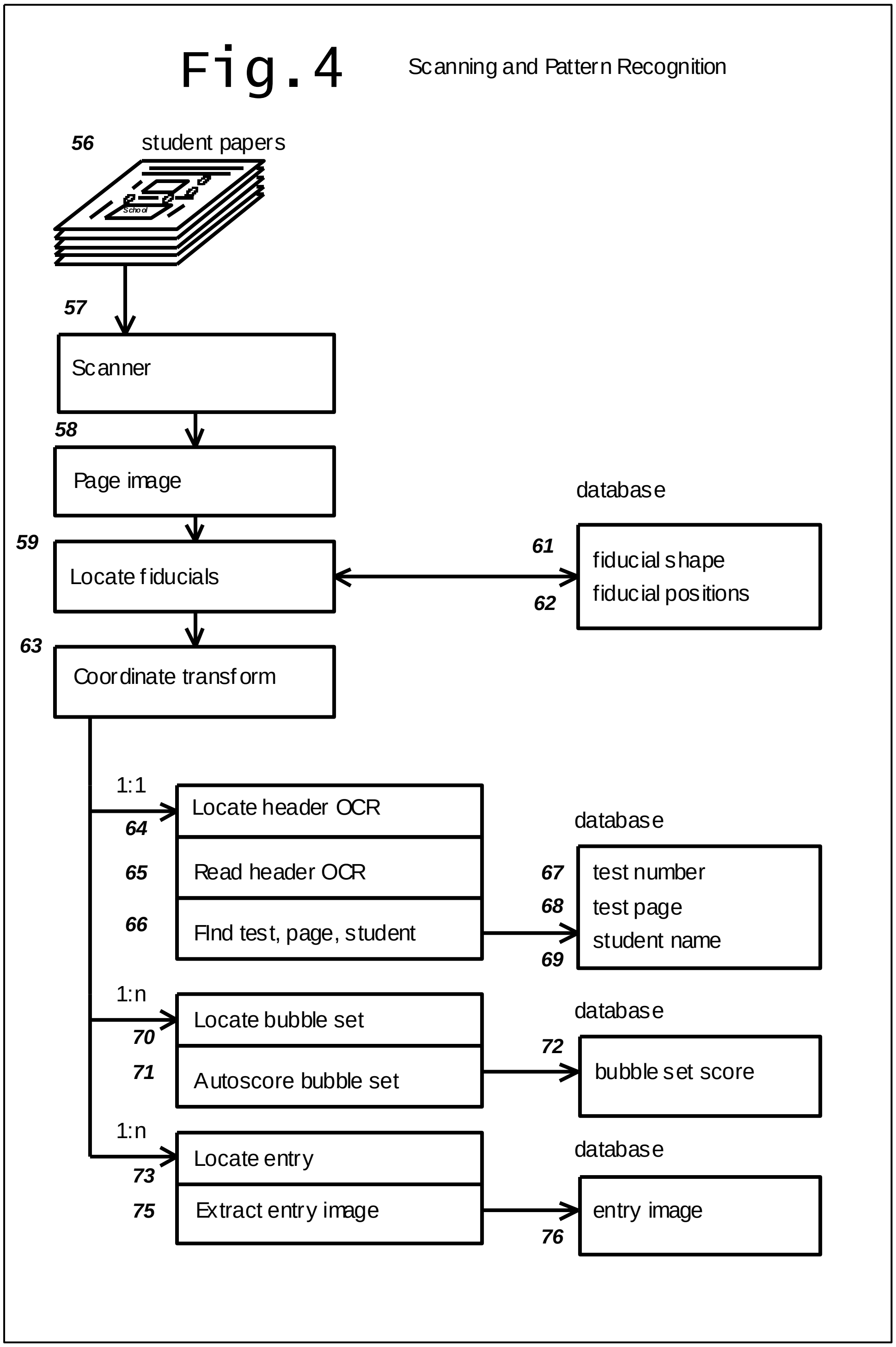
A typical test or homework page



Witnessed and understood: ______________________________ Date: __________

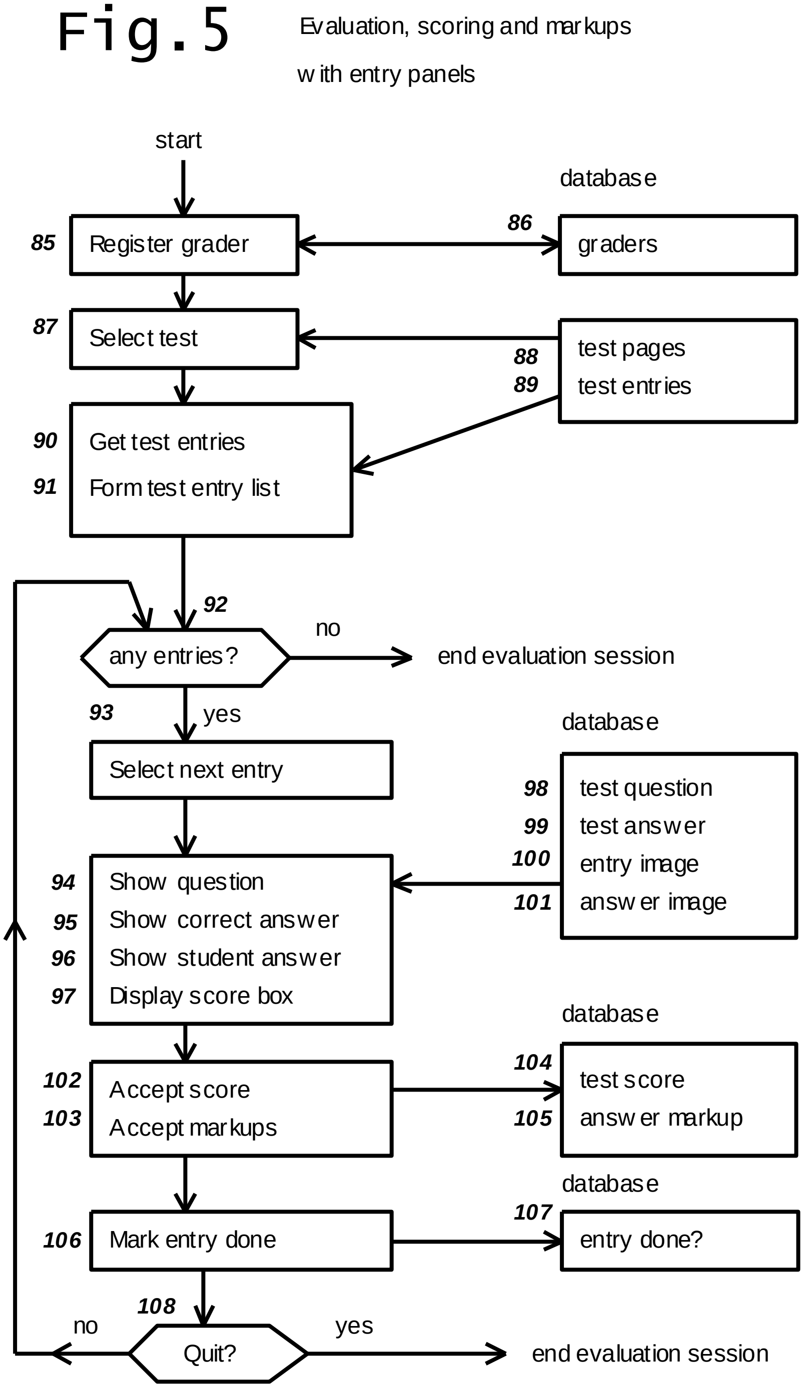


Witnessed and understood: ______________________________ Date: __________



Witnessed and understood: ___________________________ Date: _________

Fig.5



Witnessed and understood: ___________________________ Date: _________