Development of Teaching Materials for Field Identification of Plants & Analysis of Their Effectiveness in Science Education

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THERE exists a variety of methods for identification of plants as described in detail elsewhere (Tilling 1984). Among those methods two major approaches emerge, one utilizing dichotomous keys and the other synoptical keys (Kanai 1962, 1989; Ono & Kojima 1979). In general, the former corresponds to single-access keys, the latter multi-access keys. Traditionally, dichotomous keys have been used for plant identification. Most books on plant taxonomy that have been published so far utilize dichotomous keys. With this type of key readers are asked to select between two choices in a predetermined series of steps. This procedure is repeated until the name of a specimen is unambiguously identified. This approach is quite useful when a specimen is presented with many characters one can use for its identification.

Synoptical keys, on the other hand, utilize a set of characters a specimen on hand actually possesses (Kanai 1978a; Pankhurst 1978; Ono & Kojima 1979). One can observe any number of characters among the keys in an arbitrary order for identification; hence this method is easy to adopt even if some of the characters are missing in the specimen and the user's knowledge cannot make up for the missing information.

Still, synoptical keys are not as widely used as dichotomous keys because the space required for all the characters used for synoptical keys is much larger than that for dichotomous keys (Kanai 1962, 1978b). The author believes, however, that the application of computers and electronic data storage would easily solve this space problem. Plant names and their characters are stored in a two-dimensional matrix, a data structure readily created by relatively simple computer programs. The content of the matrix is easily edited, and retrieval of information for a specific plant is straightforward. A large selection of software is also commercially available for manipulation of matrices.

This paper presents teaching materials developed on personal computers for field identification of plants with synoptical keys; it is targeted at novice users such as students at junior and senior high schools. The rest of the paper describes a series of steps taken to develop such materials. A mother data matrix was first created with software developed by the author, compiling many observations of plants and sorting their characters in a way easily understood by beginners. According to the actual area where field study was to be conducted, a submatrix was then extracted containing only those plants found in that area. The submatrix thus extracted will be referred to as "the identification table" for the rest of the paper. The identification table is compact and fits on one page (size 8½″ × 11″), making it easy for students to use.

Then, punched cards were created based on the data in the identification tables, to be used during identification exercises in the field. There are mainly two kinds of punched cards, body-punched cards and edge-punched cards (Ono & Kojima 1979; Tilling 1984). A body-punched type was selected as it is easier to use while walking in the field.

The method was also implemented on a computer. The software allows a user to proceed with identification of specimens interactively. Besides desktop computers, notebook types were used so that the software can be used in the field.

The mother data matrix was revised repeatedly based on actual field study with students using the identification tables, punched cards and computer programs. An attempt was made to incorporate feedback from students in the revisions as much as possible to make the teaching materials more suitable for beginners.

Methods

In production of the mother matrix about 2,000 seed plants were selected as a target of an identification process. An attempt was made to choose plants

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that are relatively common and thus should be familiar to students.

Characters Employed

All the characters used are visibly identifiable. Those selected were designated by commonly used terms instead of the technical terms traditionally used so that beginners can easily recognize them.

Characters were roughly categorized for beginners to easily make a choice. Those characters prone to subjective interpretation, such as texture, thickness, or softness of leaves, were excluded in general, except for a few cases described later.

For identification of species of seed plants, 51 characters were used from infant to ripe phase. These characters were classified into 13 items, graphically shown in a table in Figure 1.

Note that a user may add or exclude items or characters as needed. With an anticipated increase in the number of items or characters in the future, a two-digit number was assigned to each item and a four-digit number to each character. Following is a description of how the main characters from Figure 1 were determined.

1. Shape of Leaf (Item 30). Shapes of leaves were classified into seven types of characters. The "simple leaf" type was further divided into two sub-categories, one "long" (Character 3001) and the other "not long" (3002). Among simple leaves, those that are more than five times as long as they are wide belong to the "long" category. Compound leaves were classified into three sub-categories based on the number of leaflets or the whole shape: "three to five leaflets" (3003), "pinnate leaflets" (3004), and "many leaflets with complex shape" (3005).

There are generally two types of incision, the pinnate incision as in dandelion or the palm-like incision as in maple; however, borderline cases between those two categories are hard to classify. Therefore, all types of incision were grouped into a single category, "has incision" (3006). In the case of compound leaves, a user should observe leaflets for the existence of incision. Cypress, spike-rush and saprophytic orchids only have leaves that look like scales. These plants were assigned to the same type, "only scale-like leaf or leafless" (3007).

2. Nerve of Leaf (Item 31). Traditionally dicotyledons are said to have mesh-like nerves and monocotyledons parallel nerves. Actually, both groups do have fine mesh-like nerves and only very distinct cases in those groups can be categorized as such; however most dicotyledons looked like fishbones, hence they were assigned to the "fishbone-like" category (Character 3101).

When more than one distinct nerve was observed starting from the leaf base, two categories were con-

sidered, "palm-like" (3102) and "parallel" (3103). The former is for wider leaves such as those of maple and the latter is for narrow leaves such as those of grasses. Those leaves having only one distinct nerve at the center of leaves or no distinguishable nerves were grouped together into the same category (3104). Leaves that are long, narrow and thick generally belong to this category. In the case of compound leaves, nerves were observed in leaflets.

3. Smell of Leaf (Item 36). The smell of a leaf is rather a subjective character. Yet this character was found to be quite effective for identification of plants having a strong and distinctive odor such as onion and mint. Thus the single category "has distinct, strong smell" (Character 3601) was included in the table.

4. Color of Flower (Item 50). Colors of flowers were categorized into three basic groups: "red" (Character 5001) for red, peach or purple flowers (as in azalea); "yellow" (5002) for yellow, orange, yellow-green, green and brown flowers (as in dandelion); and "blue" (5003) for blue or light-blue flowers (as in gentian). In addition, the "white" category (5004) was added.

5. Shape of Fruit (Item 71). Three categories were included for this item. The "cone-like" category (Character 7101) was created mainly for the gymnosperms. Some angiosperms such as birch, plantain and sedge also have cone-like fruits and therefore these plants were included in this category.

The "has shape like common edible vegetable, fruit" category (7102) tended to draw rather subjective judgment. However, users seem to enjoy identifying this type so it was included in the table. Note that identification was strictly visual, and it is irrelevant whether the fruit of a specimen is actually edible or not.

The "thorned, winged, long-haired" category (7103) was found to be effective for identification of such families as yam, maple, starwort and grass.

Determination of Characters for Each Plant

Next, an attempt was made to select characters of each plant. Since there is considerable variation of characters within the same species, wild plants in fields, specimens stored in the herbarium of the National Science Museum, Tokyo, and illustrations in several prominent plant encyclopedia were examined in order to identify the category to which a character of each plant belongs for the set of items chosen for the table.

Selection of characters was based mainly on how beginners would observe characters of plants rather than on morphological accuracy. Figure 2 shows a part of the mother data matrix thus compiled. The
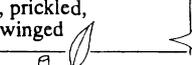
It. No.	Item	Char. No.	Character	It. No.	Item	Char. No.	Character
10	stem shape	1001	tree	34	petiole	3401	petioled
		1002	herb			3402	sessile
		1003	vine,	tendril, runner			3403	stipuled
		1004	thorned, prickled, awned, winged			3404	sheathed or amplexicaule
11	stem section	1101	round	35	phyllo-taxis	3501	alternate
		1102	square			3502	opposite
		1103	triangular			3503	verticillate
		1104	tubular			3504	fascicled
		1105	with milk			3505	radical
30	leaf shape	3001	simple leaf, long $a > 5b$	36	leaf smell	3601	smelled
		3002	simple leaf, not-long $a < 5b$	50	flower color	5001	red series
		3003	compound leaf with 3–5 leaflets			5002	yellow series
		3004	pinnate compound leaf			5003	blue series
		3005	multi-compound leaf			5004	white
		3006	lobed or incised	51	flower shape	5101	actinomorphic
		3007	scale-like leaf or leafless			5102	zygomorphic
31	leaf nerve	3101	fishbone-like			5103	petal 0–4
		3102	palm-like			5104	petal 5
		3103	parallel			5105	petal 6 or more
		3104	only midrib disctinct, or nerve indistinct	70	fruit color	7001	red series
32	leaf margin	3201	serrate or undulate			7002	yellow series
						7003	blue series
		3202	entire			7004	white
						7005	black
33	leaf base	3301	emarginate or cordate	71	fruit shape	7101	cone-like
		3302	truncate, cuneate or attenuate			7102	vegetable or fruit-like
						7103	thorned, winged, long-haired

Figure 1. Character table of seed plants for identification of species. Each item, such as the shape of leaves, is designated by a 2-digit number. A set of characters is further identified by a 4-digit number, with an additional 2-digit character number concatenated with a corresponding item number.

Plant No.	Plants name 1 Japanese name	Plants name 2 English name	Plants name 3 Scientific name
1	AI	———————	*Polygonum tinctorium*
2	AIASHI	———————	*Phacelurus latifolius*
3	AIZUSHIMOTSUKE	———————	*Spiraea chamaedrifolia var. pilosa*
4	AINAE	———————	*Mitrasacme pygmae*
5	AIBASOU	Bulrush*	*Scirpus Wichurai*
6	AOIGOKE	———————	*Dichondra repens*
7	AOISUMIRE	Violet*	*Viola hondoensis*
8	AOKAMOJIGUSA	Wheat-grass*	*Agropyron ciliare var. minus*
9	AOKI	Japanese Aucuba	*Aucuba japonica*
10	AOGIRI	Phoenix-tree	*Firmiana simplex*
11	AOSUZURAN	Helleborine*	*Epipactis papillosa*
12	AOTSUDURAFUJI	Coralbeads	*Cocculus trilobus*
13	AONOKUMATAKERAN	Indian Shell-flower*	*Alpinia intermedia*
14	AONOTSUGAZAKURA	———————	*Phyllodoce aleutica*
15	AOHADA	Holly*	*Ilex macropoda*
16	AOMIZU	Richweed*	*Pilea mongolica*

Figure 2. Portion of mother data matrix. Plants are listed in the rows of the table. The mark "o" below the column of a character number indicates that a plant has a specified character. The space is left blank otherwise. English and scientific names of the 2,172 plants listed in the table are shown in a table below, with genus indicated by an asterisk. Otherwise names are for species. Items, item numbers and character numbers are the same as in Figure 1.

mark "o" indicates that a plant has a specified character; otherwise the space is left blank. In some cases multiple characters were allowed to be selected simultaneously for the same item.

Production of the Mother Data Matrix

The mother data matrix on 51 characters from about 2,000 species of seed plants was created with software developed by the author. The data for the matrix were stored in files, and the matrix was also made available as hard copies.

Production of the Local Identification Tables

From 50 to 200 seed plants were selected in the targeted area such as a schoolyard or specific wild field. The number of plants selected depended on the number of plants in the targeted area. Selected plants and their data were extracted from the mother data matrix by software developed by the author to produce a local identification table. Note that the format of a local table is identical to its mother matrix.

Production of the Identification Card

Body-punched identification cards (10 cm × 15 cm in size) were created using the data from the identification table for use in field study. Figure 3
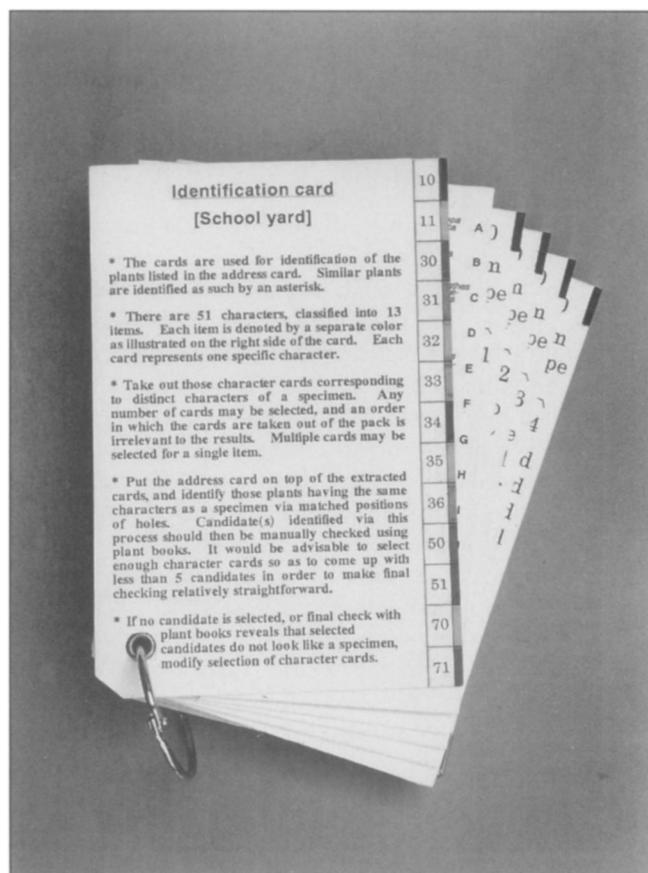

Figure 3. Overall view of body-punched identification cards.

illustrates an overall view of the cards. The cards consist of a cover, an address card of the plants, and character cards. The cover specifies the name of a targeted area, how to use the cards, and 13 items denoted by different colors. The plants from the identification table are listed on the address card, with holes below their names as shown in Figure 4a. Each character card represents a specific character; and a plant having that character, as specified in the table, is denoted by a hole in the same position as that of its name in the address card. Figure 4b illustrates an example of character cards. Either a drill or hand puncher was used to make holes at precise locations. On the right-hand side of the cards is one of 13 color-coded blocks specifying an item. In the lower left corner is a hole made to hold all cards together with a ring so that it is possible to use them while walking in the field.

Production of the Identification Programs

Based on the data in the identification tables, the plant identification programs were developed in BASIC using the algorithm shown in Figure 5. Figure 6 illustrates an example of the format of data. Desktop computers were used in a classroom whereas notebook types were chosen for field work.

Study in Classroom or Field Using the Tables, Cards & Programs

Figure 7 summarizes how to use the identification table. First, one puts a piece of paper just below the columns with the character numbers. Paper with lines separating items would make it easier to align paper with the numbers. One then marks "o" on the paper below the numbers of characters observed in the specimen. It is possible to mark more than one type of character for the same item. Next, one slides the paper downward searching for the plant(s) with the same set of "o" marks as the specimen. Note that it is common to have fewer "o" marks for the specimen than any of the plants in the table. The plant with the largest number of common "o" marks is the most likely candidate matching the specimen.

To identify plants with the cards, one takes out the cards corresponding to the characters of the specimen instead of making "o" marks. One then puts the address card on top of the extracted cards and identifies those plants having the same characters as the specimen via matched positions of holes. As with the table, one may choose more than one card for multiple matching of characters for the same item. The order in which cards are extracted does not affect the outcome of identification. When using the cards it is easy to distinguish cards incorrectly
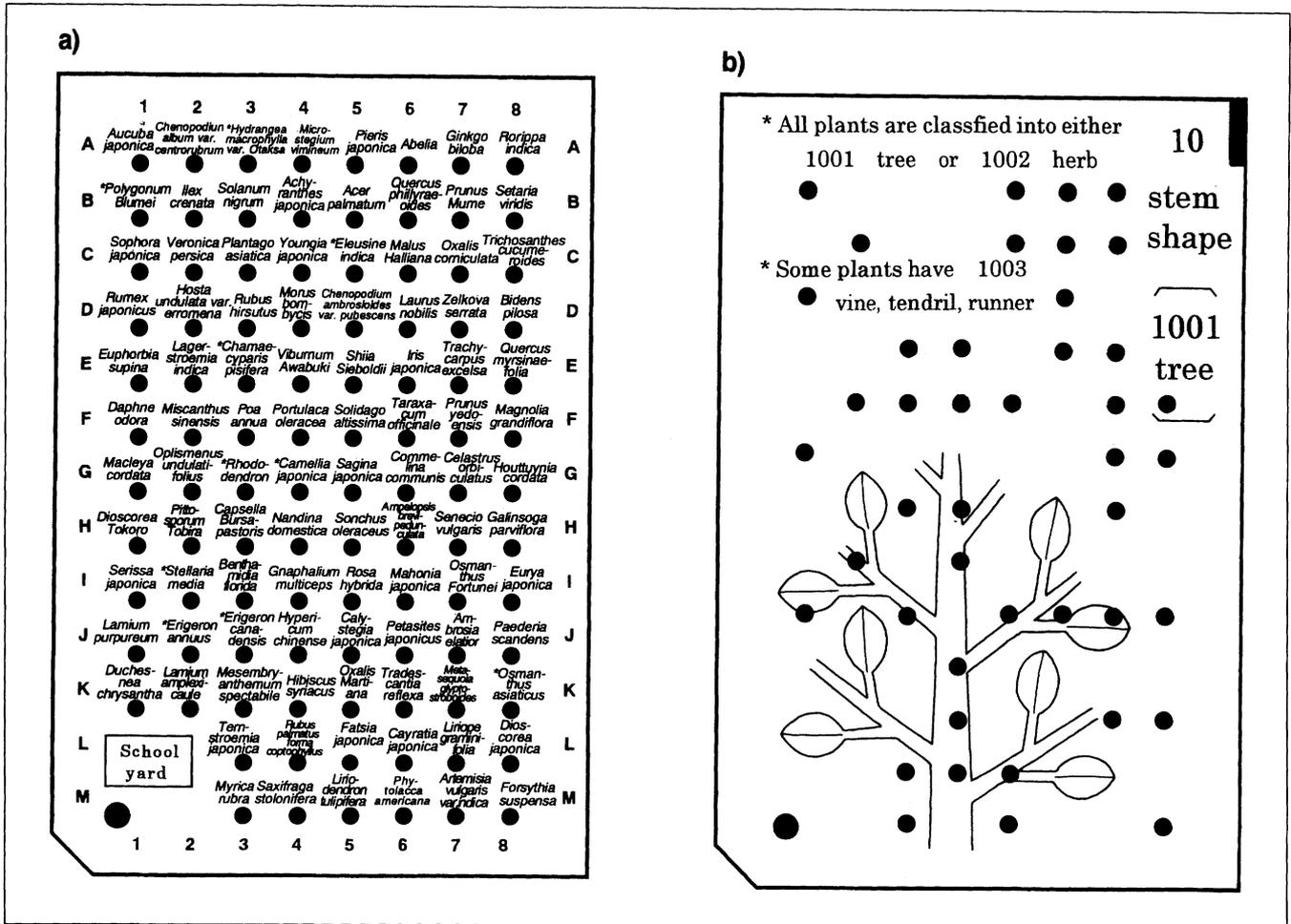
Figure 4. a) Address card specifying a position of each plant. Characters of a plant are specified by holes in corresponding character cards in the same position, as determined by the location of that plant in the address card. b) An example of character cards for "tree." All trees have holes in this card in the positions corresponding to the holes under their names in the address card.

selected by looking through the holes and identifying a few cards obstructing them for likely mistakes.

With the programs, users only have to type in selected character numbers from a keyboard, as illustrated in Figure 8a. The specific number of characters typed in or the order in which the character numbers were entered does not affect the outcome. Having processed the input, the program returns and displays name(s) of matched plant(s) as shown in Figure 8b. If no candidate shows up on the screen users can try to find out what character(s) were identified incorrectly and re-enter correct character number(s). Character numbers entered earlier can be canceled at any stage by the software, in order to accommodate frequent typographical errors made by students.

Whether the tables, cards or programs are employed, users should refer to illustrations in plant books in order to check candidate(s) against the specimen. In this study, special booklets were compiled that contained only plants in the local identification tables for an efficient final check. It is of course possible to use commercially available plant encyclopedias for this purpose.

The table is suitable for use in a classroom in an identification process exercise. Such exercises were conducted using the table for 50 plants in schoolyards of two junior high schools. The cards were used effectively in both schoolyards and fields, compiled separately for each designated area. Programs were used effectively in classrooms, schoolyards and fields, with software customized for each area and a suitable choice of hardware. Combinations of different types of teaching materials were also used to further improve effectiveness.

Students typically went through preliminary exercises first, practicing use of the table, the cards or the programs with an example plant whose characters are very distinct. In this study, Japanese Maple was often chosen as an example. Students learned in such preliminary exercises how to identify distinct characters suitable for consideration, when to pass up items or to make multiple selections when characters cannot be easily classified into categories, and what goes wrong when mistakes are made in identifying characters, leading to wrong or no candidates. For an effective exercise, it was sometimes necessary for
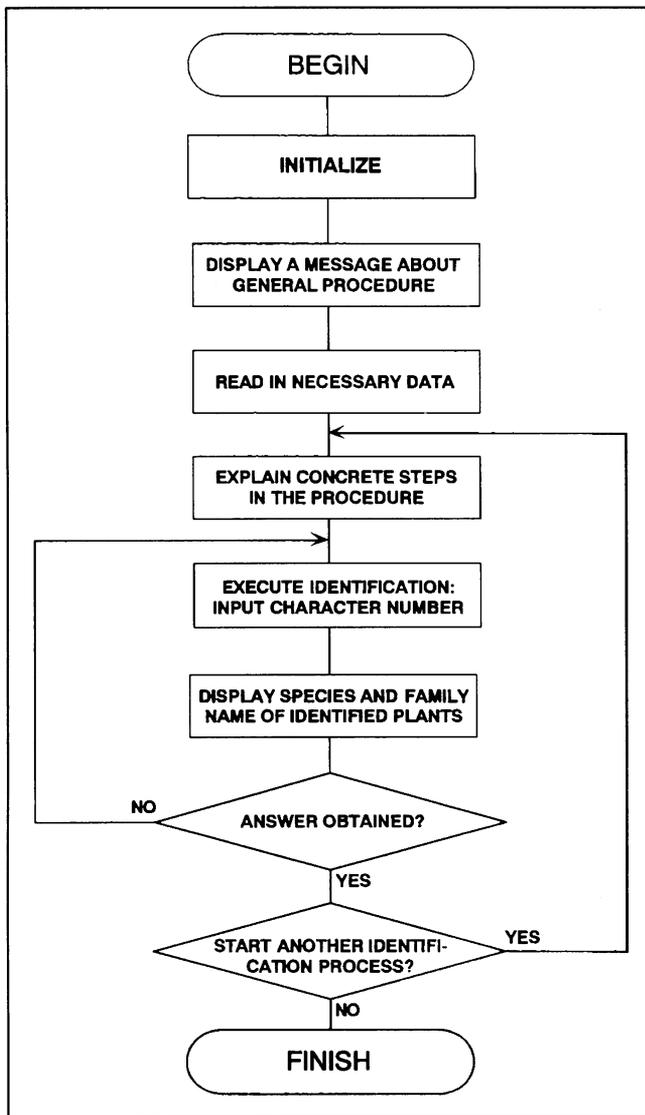
Figure 5. Flow chart of the plant identification program.

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10000 DATA 100, 51
10010 DATA 1001, 1002, 1003, 1004, 1101, 1102, 1103, 1104, 1105
10020 DATA 3001, 3002, 3003, 3004, 3005, 3006, 3007
10030 DATA 3101, 3102, 3103, 3104, 3201, 3202, 3301, 3302
10040 DATA 3401, 3402, 3403, 3404, 3501, 3502, 3503, 3504, 3505, 3601
10050 DATA 5001, 5002, 5003, 5004, 5101, 5102, 5103, 5104, 5105
10060 DATA 7001, 7002, 7003, 7004, 7005, 7101, 7102, 7103
11000 DATA    1   Aucuba japonica , 16
11010 DATA 1001, 1101, 1102, 3002, 3101, 3201, 3302, 3401, 3502, 5001, 5002, 5101, 5103, 7001
, 7002, 7102
     :
12980 DATA 100   Forsythia suspensa , 18
12990 DATA 1001, 1003, 1101, 1102, 1104, 3001, 3002, 3003, 3101, 3201, 3302, 3401, 3502, 5002
, 5101, 5103, 7002, 7103
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Figure 6. An example of plant data in the program. Line 10000 has a number of plants and of character numbers. Lines 10010–10060 have 51 actual character numbers. Line 11000 from left indicates plant number, plant name, and a number of character numbers for the plant. Line 11010 has all the character numbers for the plant specified directly above. Plants are exchangeable, and character numbers can be added or modified easily in data files.
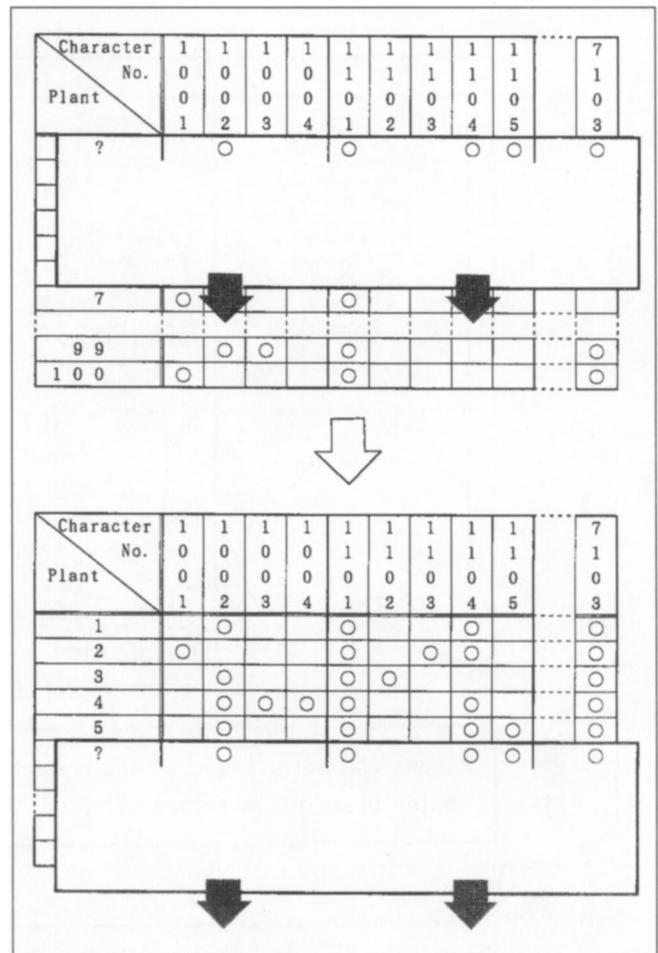

Figure 7. Identification process using a table. First, one puts a piece of paper just below the columns with the character numbers and marks "o" on the paper below the numbers of characters observed in the specimen. It is possible to mark more than one type of character for the same item. Next, one slides the paper downward searching for the plant(s) with the same set of "o" marks as the specimen. Though it is common to have fewer "o" marks for the specimen than any of the plants in the table, Plant 5 in this example appears to provide an exact match to the specimen. The process continues until all the plants are compared to the specimen.

teachers to describe to students how to distinguish characters of plants (e.g. the difference between a single leaf and a compound leaf) beforehand. After the exercises, students reported their results, along with their opinions and feedback.
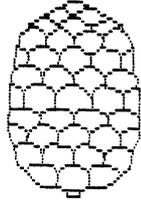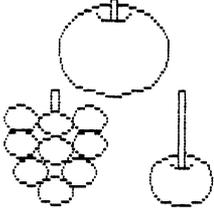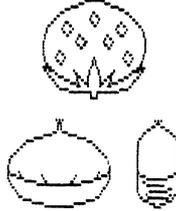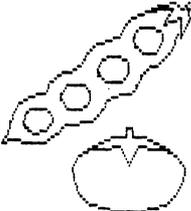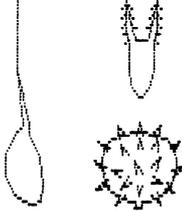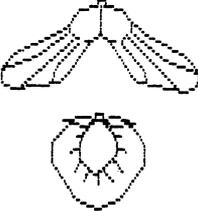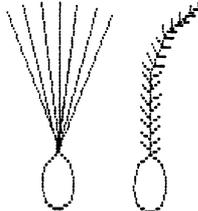
Local identification tables, cards and programs were created for specific schools and areas at the request of teachers unfamiliar with identification of plants to facilitate exercises.

Results & Discussion

Identification of Japanese Maple

As shown in Figure 9, Japanese Maple is characterized by a set of categories consisting of "tree"

a)

7101 Cone-like Pinecone, etc.	7102 Fruit-like Apple, etc.	7102 Fruit-like Strawberry, etc.	7102 Vegetable-like Bean, etc.
	7103 Thorned Burrweed, etc.	7103 Winged Maple, etc.	7103 Long-haired Mum, etc.

Input character numbers, and press return. When finished, or there is no match, enter 0 and press return 7103<CR> [1]

b)

Plants matching input character numbers are displayed in an alphabetical order.

1001   1101   3006   3102   3201   3301   3401   3502
7002   7103 [2]

    Japanese Maple

There is one plant matching all the selected character numbers.

Do you want to add more character numbers? If you made a mistake when entering character numbers, type"-<Character number><CR>" (e.g.,-3001<CR>) to delete them (y/n) n<CR> [3]

* *
    Check the identified candidate against the specimen using a plant book.
    If in doubt, repeat the process.
* *

Figure 8. An example of an identification process using a computer program. a) Example input for a shape of fruit. The characters displayed are the same as those listed under item number 71 in Figure 1. b) Output of the results. At this point character numbers can be added or deleted, if needed. 1) <CR> is a Carriage Return. 2) Those character numbers (1001 to 7103) were selected by comparing the specimen to a set of all characters displayed for each item (see Figure 1 for possible characters in each item). 3) If "y (yes) <CR>" is entered, a message appears according to which one may add or remove character numbers and repeat an identification process.

Item No.	Item	Cha. No.	Character	Item No.	Item	Cha. No.	Character
10	stem shape	1001	tree	50	flower color	5001	red series
11	stem section	1101	terete	51	flower shape	5101	actinomorphic
						5104	petal 5
30	leaf shape	3002	simple leaf, not-long				
		3006	blade lobed	70	fruit color	7002	yellow series
31	leaf nerve	3102	palm like	71	fruit shape	7103	winged
32	leaf margin	3201	serrate				
33	leaf base	3301	emarginate				
34	petiole	3401	petioled				
35	phyllotaxis	3502	opposite				

Figure 9. Characters of Japanese Maple used in field studies with students.

(Character 1001), "round" stem section (1101), "simple leaf, not-long" (3002), "blade lobed" (3006), "palm-like" leaf nerve (3102), "serrate" leaf margin (3201), "emarginate or cordate" leaf base (3301), "petioled" (3401), and "opposite" phyllotaxis (3502). If all those characters are correctly identified the single candidate, Japanese Maple, is obtained in the all teaching materials.

In spring when the Maple has flowers, categories "red series" flower (5001), "actinomorphic" (5101), and "five petals" (5104) are used for them. In Autumn, categories "yellow series" fruit color (7002) and "winged" fruit (7103) are used. In both cases additional categories also result in the single candidate.

When multiple categories can be chosen for the same item students tend to choose only one of them. For example, Japanese Maple may be characterized as either "simple leaf, not-long" (3002) or "blade lobed" (3006), though most students chose only 3006. In this case adding 3002 for identification of the Maple does not make the outcome of an exercise different. However, the number of candidates generally decreases when an increased number of characters is observed. This point should be emphasized prior to the exercise.

Most leaves of the Japanese Maple have a base that is "emarginate or cordate" (3301); some of them, however, actually can be identified as "truncate, cuneate or attenuate" (3302). Students can choose both characters or can pass up the item.

Some students chose "fishbone-like" leaf nerve (3101) by observing only leaf lobes. This choice led to no candidate. Choosing incorrect cards also led to wrong candidates in some cases, though by looking them up in books students were likely to realize that they had come up with wrong answers. In such cases wrongly selected characters are to be removed or replaced by correct ones.

Addition or Exchange of Plants or Characters

As exercises were repeatedly performed, addition or exchange of plants or characters was sometimes needed. It is easy to add or exchange plants in the table. In the case of the cards, it is rather difficult to add plants if there is no space left in the address card. However, if there are plants no longer applicable to the area one can remove them from the address card to make room for new plants. One then just has to fill the holes for old plants and make new holes for newly added plants in applicable character cards. In the case of the programs, addition or exchange of data is easily handled by editing data files (see Figure 6 for data format).

Feedback from Students

Figure 10 shows students participating in field exercises, using notebook computers in the schoolyard. The characters selected in such exercises were reported by students afterward, making it possible to identify the trends in the selection. Based on such feedback the mother data matrix was repeatedly revised, as were the table, cards and programs.

Figure 10. Exercise by students using notebook computers in the schoolyard.

In the exercises performed at a high school in 1986 an average rate for correct identification using the cards was 83%. The rate has continued to rise since then and is expected to do so in the future. Most students seemed to find it very valuable to have an opportunity to observe nature in detail. They also came to feel familiar with the plants they identified, which was considered a major achievement of the exercises.

Even when teachers conducting the exercises were unfamiliar with the identification of plants, students easily learned how to use the teaching materials described in this paper in a short period of time and enjoyed themselves in the exercises (Iwasaki 1984). Thus the identification tables, cards and programs seemed rather useful not only for students but also for teachers who have very little experience with the identification of plants themselves. Currently the programs are widely used in various exercises and training.

Conclusion

This article has described the field identification of species of plants using an identification table, cards and programs. The exercises with the developed materials turned out to be a fun and satisfying experience for students when they could identify plants with their names, and also were very effective in helping students feel close to nature. In addition, the developed materials were quite useful for teachers unfamiliar with identification of plants. Note that the methodology of identification described in this paper can be applied not only to plants but also to other areas of biological identification, or even to other scientific disciplines. The method is currently being extended to the identification of plants at the level of families, which will be reported elsewhere.

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Appendix

The current version of the program is written in DOS-BASIC and runs on PC-98 (NEC) or FM (Fujitsu) personal computers. (A new program, which is different from the one reported in this article but based on the same algorithum/data and runs on Microsoft™ Windows® 3.1/95/98/NI, was developed. The details on this new program can be obtained from the author upon request.) Its user interface is designed for Japanese users with all the information currently presented in Japanese. A new version is currently being developed that supports a user interface in English and runs on an IBM PC (AT) or its compatibles, which should be available by the end of 1997. The programs are managed and maintained by the Information and Research Center for Educational Software, 1-30-16, Ebisunishi, Shibuya-ku, Tokyo, 150-0021, Japan, and available for nominal fees covering actual expenses such as shipping and handling. The programs can be requested directly from the Center via fax (fax number: + +81-3-3464-2302) or in writing. Interested readers may also contact the author directly at the address listed at the beginning of the article either in writing or by sending e-mails for a copy of the programs and general information such as future revisions.