Science
Teaching Methods

Fourth year students

(General Education)

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(1) :Discrepant events

What is a discrepant event?

- Everyone has seen water run downhill . The fact is hardly surprising or unusual , if you were to see water run uphill , it would be an entirely different matter , *water flowing against the force of gravity is a discrepancy.*

- Most people know that water freezes at 0 degrees Celsius (32 degrees Fahrenheit). But what if you were to see ice melt at 10 or 15 degrees below the freezing point? What would you think ? Again, *there would be feelings of surprise and curiosity*.

- Water is expected to run downhill , not uphill , ice is expected to melt above 0 degree Celsius , not 10 or 15 degrees below 0 . These are examples of discrepant Events . Such events are best *described as being unexpected , surprising or paradoxical.*

- A good discrepant event tends to create *a strong feeling* In the observer .generally , there will be an inner feeling of " wanting to know", . It is obvious that when pupils are Strongly motivated , conditions are conducive to inquiry learning .

How to use discrepant events to promote process and inquiry?

inquiry is the " shifting (of) emphasis from t*eachers presenting* information ….

To students learning science through *active Involvement* "

What is process?

It is " how a scientist works, thinks, and studies problems.

In other words , it is a methods of investigating. The *process approach includes many specific skills, includi*ng for example the following:-

(Analyzing- classifying- collecting data – communicating- comparing- controlling variable –demonstrating – describing-drawing conclusion- estimating- experimenting) .

Discrepant events become quite useful when :-

1 . *Set up a discrepant event.*

in_this step events are presented to *gain attention ,increase motivation and encourage pupils to seek ways* of solving the discrepancy.

*The stage is set for learning b*ecause pupils are confronted with questions or problems they will want to resolve , they will want to know the answer to a good discrepant event.

2 *. Pupils investigate to solve the discrepancy*.

After the Event is properly introduced , the pupils will be *anxious to seek an answer ,* in attempting to *resolve the discrepancy* , pupils will often engage *in meaningful inquiry*. They will be active in(observing ,recording data, classifying, predicting , experimenting, and doing)

. In addition , it is likely that they will learn much of the *real scientific content* of the lesson

3 . *Resolve the discrepancy* .

with some luck ,pupils will *Resolve the discrepancy* as a result of their own *Investigation.* In other words , by their own direct ac*tivities and experiences* they will *find the answer* to Many of the questions posed by the discrepant event.

Example (1)

; why does the coin " disappear" when water is poured into the beaker.

1. Set up discrepant event. Place a coin under a clear beaker or jar and tell the pupils to watch the coin closely . It is easily to visible when viewed through *the side of the glass* . Now pour water into tumbler and " presto " the coin disappears , repeat several times to be sure that all can see.

An event such as this has great value in motivating pupils .as a result ,such an activity is an ideal for introducing a science lesson . From this point on , *the inquiry , or wanting to know , come from the* pupils.

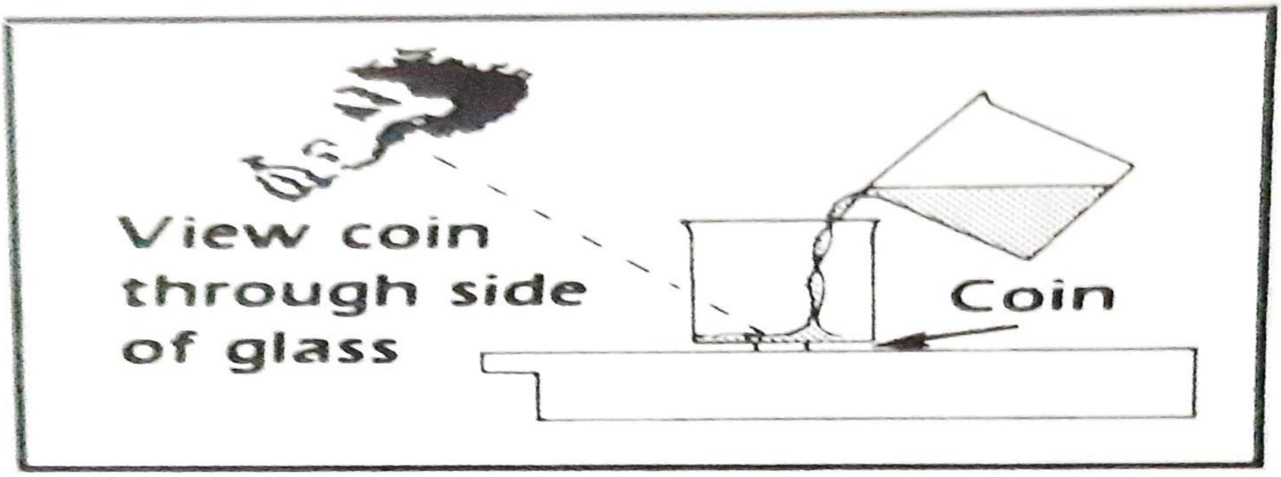


Fig. 1–1. **Why does the coin "disappear" when water is poured into the beaker?**

2. *Pupils investigate to solve the discrepancy*. they are *self-motivated* and eager to find *out how it work*. Their Involvement at this stage of a lesson is true inquiry , it will include *(questioning, recording data, graphing ,Predicting , experimenting)*.

In this particular event the pupils will observe that:-

a. the coin *disappear*s from the view when the tumbler is filled with water but only if viewed through the side of tumbler.

b. The coin *still visible* if viewed from above . They will find that it makes no difference whether the water is poured quickly or slowly although if *poured* slowly , the coin seems to move upward slightly before it vanishes.

3 . Resolve the Discrepancy.

Under an ideal setting pupil will gradually resolve the questions as they work on step 2.their findings should then be placed into the proper context in step 3 . They should be led to see how the event relates to broader *scientific framework*.

The event with the disappearing coin is pertains to the refraction or bending of light .refraction occurs when light moves at an angle from one medium (a substance that allows light to pass through it) to another. When Viewed through the side of the glass ,the light travels Several different mediums (glass, water, and glass again) and is bent inwardly so much that the light from the coin never reaches outside the glass when viewed from the top, however , the coin is still Visible because there are only two medium s. also since the light travel from one medium to another at only a slight angle , there is not as much bending as when it pass through at a sharp angle.

Pupils investigation may include the following process.

1.Observing that the coin disappears from the view when the fluid is poured into the glass.

2.*Checking* to see that the coin is still under the glass.

3*.Verifying* that water works the same as the disappearing fluid.

4*.inferring* that water makes the image of the coin disappear.

Example .2.

antigravity fountain. Set up an arrangement of containers and tubes as shown in figure.

Start with5 to 10 centimeters of water in the inverted top bottle and then open the clamps. The fountain begins to flow in the top container. Why?

Pupil investigation :

1*. Observing* that container c fills with water.

2.*Observin*g that container B empties out.

3. *Recording* with diagram the path of the water from B through A , into C.

4. *Forming a theory* to explain why water goes uphill from

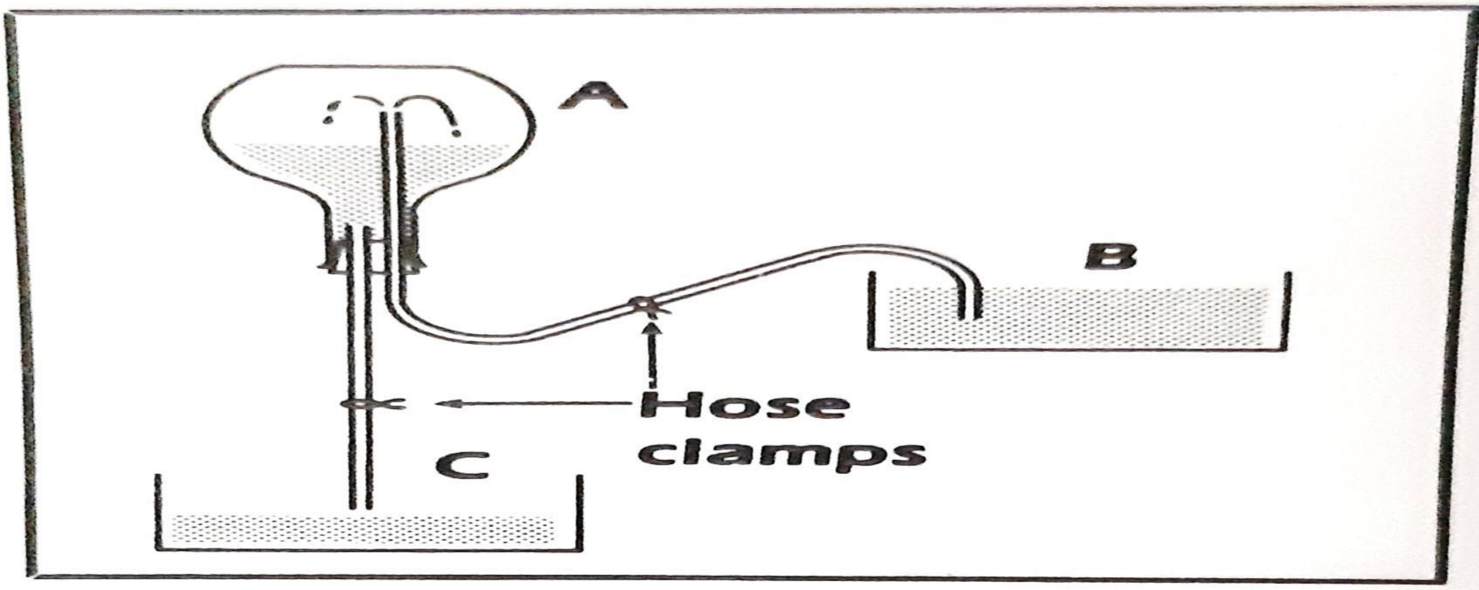


Fig. 9–8. **Why does the water run uphill from container B to A?**

Context(air exerts pressure)

Event explained in context (air exerts pressure).

This event is more dramatic because it forms a fountain in the upward part of its journey .

Note : if you Use an ordinary glass tube for fountain , it will drain the water in container B rather quickly . If however you narrow the opening of the glass tube in the flame of Bunsen burner, or even if you just use the glass part of Eye dropper, the event will run for quite a while before container B empties.

Point out that some outside force must be causing the water to go uphill in both events.

Gravity is obviously not that force because gravity would push the water “ downhill” not up . What provides that force?

It may be easier to understand what happen by starting at the top flask of event and working backward ,open the clamp , and water flows out , leaving behind a partial vacuum in the flask . Air tries to get in to fill that vacuum but water is in the way . Since container B is higher than C, it takes less pressure to push the water in from B than from C.. thus the path is set in which The water moves from container B to the top flask and down to the bottom container.

(2) :New trends in teaching science

1-Experimenting in the science teaching

In fact ,experimentation should be a major way of obtaining concepts and generalization for pupils this is true for the following reasons:

1-.scienists in laboratory setting perform experiments as a means for gathering information .

2-.problem solving can be emphasized in teaching science such as identifying a problem ,gathering information pertaining the problem

,developing a hypothesis , testing hypothesis and developing needed modifications or revisions of the stated hypothesis.

3.-Pupils must develop skills relating to critical thinking when content is evaluated.

—4-.pupils need to become careful observers in ongoing learning activities involving science .pupils should carefully observe what is happen during the the experiment and base their conclusion on what have been observed. Pupils may be guided to observe facet of the following:

a. Leaves ,rocks ,and minerals, different kinds of soils, trees, grass, and clouds.

birds ,fish, turtles, frogs ,and diverse animals included in the category of mammals.

c. Animals with backbones such as worms, bees, crabs, spiders and ants

d. The hardness of different kinds of rocks and minerals

e. Objects and items attracted or repelled by magnets.

2-Reading content in science

Pupils gains much valuable content in science through reading ideas .reading sources in science may include the following:

1.-secondary school science textbooks

2-.general encyclopedia as well as science encyclopedia.

3.-Library books containing science content.

4-.pamphlets,leaflets and related sources and related sources containing content in the area of science.

When reading content in science , pupils needs to read for a variety of purposes such as :

1.-Gaining relevant concepts ,e.g. liquids . Solids , gases, electrons, protons, neutrons, compounds, and elements

2-.Acquring generalizations e.g. liquids ,solids , and gases basically expand when heated. There are exceptions , such as water, a liquid turning to ice, a solid

3-.Gaining facts e.g. stegosaurus, allosaurus, tyrannosaurus and the brontosaurus were dinosaurs that lived during the Mesozoic era.

4-.Obtaining directions e.g. reading directions to make science equipment in ongoing unites of study, magnets, electromagnets, and develop a complete circuit through parallel and series warning.

5-.Gaining sequential ideas , e.g. reading content to notice the order of relative durations geological eras : Precambrian ,Paleozoic, Mesozoic ,and Cenozoic.

6-. Thinking critically about content read e.g. noticing factual statements as contrasted with statements of opinion or accurate statements from those which are inaccurate .

7.-Thinking creatively pertaining to ideas gaining from reading , e.g. stating a hypothesis pertaining to a problem area prior to conducting a relate experiment.

Thus the learner presents a unique original hypothesis before a science experiment is performed.

3-Conducting Excursion

The science teaching has presented abstract learning to pupils largely .it is important for pupils to experiences reality for the following reasons :

1. 1-Pupils may gain accurate concepts , generalization and main ideas.

2.- Learner desire a variety of learning activities rather than sameness in experiences.

3.- Concrete situations , such as the taking of excursions , are important of learning for pupils.

4-.Pupils may be guided to sequence their own learning s in concrete situations

Excursions should be taken under the following circumstances only

1.The place to be visited is free from danger for learners..

2. No reasonable substitution has been given for excursion in terms of other learning experiences

3. Parental or guardian permission has been given in writing for taking the excursing.

4.Adequate guide service is available to aid learners in achieve optimal development.

5.Pupils perceive reasons for taking the excursion.

There are many units of study in school science in which related meaningful excursion may be appropriate for pupils :

1.If pupils are studying a unit on " the pond community they may actually visit a pond site with teacher guidance . Prior to visiting a pond community ,the teacher guide pupils to perceive purpose of excursion. A set of pictures or filmstrip presentation may set the stage for pupils participating in the excursion .from these learning experiences , pupils may be stimulated to ask questions such as :

(a)what kind of life generally is in evidence in a pond?

(b)What is the surrounding environment like adjacent to a specific pond?

(c)How can pond communities be kept clean?

(d)How does a contaminated pond affect human beings

2-if pupils are studying a unite “preventing soil erosion”

They visit an area where:

(a) Gully erosion or sheet erosion has occurred.

(b)Steps have been taken to prevent erosion e.g., grass have been seeded , terraces have been built , strip-cropping is in evidence , and trees have been planted

4-Using construction activities

Pupils with teacher leadership should have ample opportunities to engage in construction activities in ongoing unites of study in science . The following are selected values pupils may attain from participating in construction activities :

1.eye-hand coordination may be developed by pupils . Thus psychomotor skills(use of the finer or larger muscles) are being emphasized in unites of study pertaining to science.

2-the actual making of science equipment can be psychological sound for learner s in that creativity been emphasized in science teaching

3-there needs to balance between and among cognitive ,psychomotor , and affective objectives since life itself consists of activities in three domains.

4-active involvement rather than passive learning is involved when pupils plan ,develop ,and evaluate what has been constructed in term of science equipment and material.

5- pupils participating in construction activities can open future doors to vocational interests each pupils should have opportunities to discover his /Her interest and develop these talents to the maximum possible.

5-Using films ,filmstrips ,and slides

The teacher should make ample use of audio-visual aids such as films , filmstrips, and slides. Pupils can see movement and reality in motion picture film presentation .it is difficult to stop a film presentation at a given point for discussion purposes .the use of slides and filmstrips of course , provides ample opportunities to stop presentation and discuss the contents when needed .in fact it is highly recommended that pupils raise questions and present related ideas pertaining to any frame in a filmstrip or any one slide.

The following experiences are important for pupils -prior to viewing an audio-visual presentation :

1-introductory activities . Pupils must experience selected activities prior to the audio- visual presentation in order that interest ,motivation , and purpose are developed and maintained . If pupils for example, are to view an audio-visual presentation on

“ the human body “,they may as introductory activities , participate in :

(a)Discussing how to develop and maintain good health.

(b) Using microscope to look at onion cells.

(C)developing standards for safe living in the environment

(d) Discussing foods to be eaten to maintain good health.

2-follow –up activities . After the audio-visual presentation has been completed , pupils with teacher guidance may participate:-

(a)Doing research from a variety of reference sources on developing and maintaining good health . Pupils may divide into

Committees for this activity and report their findings to member of other committees

(b) Drawing pictures of different kinds of cells, e.g. bone ,skin, and blood cells .various reference sources need investigation to provide background information .

(c)evaluating the home and school environment in terms of safety standards developed during the introductory activities.

(d) Planning and serving a meal which would stress proper nutrition for pupils.

5.Using writing activities in the science teaching

If pupils for example ,are studying a unite on plants ,animals ,and the seasons” they may engage in diverse kinds of writing experiences :-

1.develop an outline .

Each pupil with teacher direction may develop an outline pertaining to content that has been read relating to an ongoing unite of study The outline should contain a title .main divisions should include roman numeral . Subdivisions may be represented with capital letters may present the finer points of each subdivision. Hindu-Arabic numerals should present each detail. the accuracy of an outline can be checked in term of

Criteria such as the following :

(a) Does the title cover the contents of the outlines Comprehensively?

(b) Does each main division (represented by Roman numerals) relate directly to the title?

(c) does each item in the subdivision relate to the intended main division in the outline?

(d) Do the details (represented by Hindu-Arabic numerals) relate directly to the intended subdivision?

A correctly developed outline should generally follow this format:

Title

1. Main Division

A. Subdivision

B. Subdivision

1. Detail

2. Detail

11. Main Division

A. Subdivision

B. Subdivision

1. Detail

2 Detail

2- develop a written report .

The content of the outline may be utilized to develop a written report. Written reports may deal with:-

(a)Summaries of experiments conducted in ongoing units of study in science.

(b)Diary entries kept by pupils on a daily basis pertaining to understanding , skills, and attitudes acquired. Members on a committee should be rotated in writing these diary entries.

(c)Logs kept on a sequential basis relating directly to what pupils have achieved in an ongoing unit of study in science.

Content in a log would pertain to learning acquired during a longer period of time than on a daily basis , such ideas recorded once a week.

(d)Content written on a particular topic chosen by a pupil or a committee of learners . Thus in a unit on " weather and how it affects us " reports may be written on the following areas:-

What causes rain to fall. Different kinds of clouds e.g., cumulus ,cirrus , et a-Weather forecasting.-Tornadoes ,cyclones, and hail-Sleet, snow ,and forest.

The monsoon climate, Mediterranean climate, desert areas And jungle regions.

6-Art work in the science teaching

Learning activities , involving art work can do much to enrich the school science teaching. Thus ,the science teacher must provide a variety of learning experiences Involving art in the science program me.

1. Developing murals.
   pupils in a committee with teacher guidance may plan and develop a mural pertaining to an ongoing unit of study in science. thus ,if

Pupils for example are studying a unit on "animals with backbones "they may decide upon scenes involving:

(a) Diverse kind of fish.

(b)amphibians'. g, toads and frogs.

(c) reptiles ,e.g. snakes ,turtles.

(d) Various types of birds.

2-Developing friezes .

a series of pictures developed by a committee of pupils .a variety of media should be available to pupils when working on a frieze . Thus crayons ,coloured pencils , and finger paints should be readily accessible at the frieze center. if pupils for example ,are studying a unit on “ animals without backbones “ they may develop a series of illustrations(a frieze) on :,

(b) Porifera (sponges)

(c)Annelida (segmented worms),e.g. earth worm and sand worm

(d)Echinodermata (spiny animals) starfish

(e) Mollusca (shellfish) ,.e.g. Clams ,scallops, and slugs.

(f)arthropod, e. g. shrimps , lobster, crawfish and crabs.

3-Developing individual picture.

to reveal what have been learned during and after the time a unit has been Progress. if learner, for examples are studying a unit ,”the Human body and how it works”each pupil may select to develop an illustration pertaining to:-

(a)The digestive system , e.g. a carefully planned and prepared picture, using a variety of art media developed on the stomach and digestion.

(b)The circulatory system. The individual pupil may choose to complete a drawing on the heart , the blood vessels , and general circulation of the blood .

(3) :Objective in the science teaching

General objectives

First : skills objectives

1. observing.

2. Identifying problem.

3.Classifying knowledge.

4. Communicating ideas.

5. Being able to use concepts pertaining to Measurement.

6.developing inferences.

7.Thinking scientifically.

8. Using needed references source.

First :Skills Objectives:

One category of general objectives for pupils to achieve skills . Skills objectives emphasize doing something with increased refinement as indicated in the stated goals .there are definite skills that pupils need to develop in school science :-

1-Observing .it is important for pupils to become increasingly proficient in observing:-

(a) What is happening in an ongoing science experiment.

(b)What is seen in the natural environment .

(c)what is viewed in terms of content from slides , films, and filmstrips

First :Skills Objectives:

1- <u>Identifying problems</u>. learners generally reveal much curiosity by identifying problems may be identified in a variety of situations such as :

(a) Reading and viewing content from diverse audio-visual aids.

(b)Taking fieldtrips with teacher guidance.

(c) Interviewing individual who specialize in a given area of knowledge.

(d) Doing field work in science as homework.

(e)Participating in a seminar related to ongoing unit in science.

(f) Working in a committee to complete a project in school science

3-<u>Classifying knowledge</u> . Pupils need to develop skill related classifying acquired facts ,concepts ,and generalizations . Thus ,for example , a pupil studying a unit on " the changing surface of earth" should ultimately be able to classify rocks as being igneous , sedimentary, and metaphoric\

4- <u>Communicating ideas</u> .it is highly important that each pupil be able to communicate content accurately and effectively to others .In oral and written communication

Pupils need to be able to present the following kinds of content:-

(a) *<u>Outcomes</u>* of an experiment or demonstration, e, g.

what happens to selected liquids, solids, and gases when heated .

<u>(b) A report</u> .e.g. dinosaurs in their natural environment during Prehistoric years.

(c) *<u>A summary</u>* covering ideas presented in a film or filmstrip. e. g. food chain and food webs.

(d) A book review , e. g. The main organs comprising the digestive system-

Mouth and salivary glands and esophagus , stomach and liver, gall bladder and pancreas, large , small intestines , and the rectum .

(e) *Main ideas* gained during a field trip, for example , pertaining to sheet erosions , gully erosion ,and cover crops.

5- being able to use concepts pertaining to measurement . These are many chances in which pupils need to present information to others using quantitative data:-

(a) In a unit on “how weather effect us “pupils record temperature readings at a selected time during many Days. A bar or line graph should be developed to show temperature readings on each of these days . Pupils may also record the amount of rain fall during a specific Interval . Air pressure also need to be recorded on a daily basis .

(b)In a unit on “ prehistoric life” pupils with direction might develop a related chart on the history of important plants and animals such as :

- The Precambrian era : (approximately 5,000 millions of years)ago to 600 millions years ago.

- Paleozoic era : (approximately 600millions of years ago to 230)millions years ago.

- Mesozoic era : (approximately 230millions of years ago to 60 millions years ago.

- And the Cenozoic : (approximately60 millions of years ago to thpresent.)

pictures pertaining to selected plants and animals for each of these eras should be drawn on this chart by committees of learners.

(c) if pupils are studying a unit on “ the solar system”

Meaningful learning must be attached to distance of planets in sequential order from the sun. pupils may notice difference in miles of planets from each other as well as the diameter of each planet in miles :

6-Developing inferences .

it is significant for pupils to develop inferences from completed observations . Learner ultimately need to develop generalizations pertaining to numerical data ,direct observation made of natural phenomena ,content read ,recorded factual Information ,information presented on charts and table.

7-Thinking scientifically. objectives and unbiased thinking as objectives for pupils to acquire need much

Attention in science teaching. In a unit pertaining to "plants in our environment, pupils identify and study variables that

Are inherent in plant growth .these variable may be controlled when conducting experiments pertaining to what plants need in order to grow.

8-thinking scientifically :

Pupils with teacher guidance may identify variables such as :

(a) The kind of soil.

(b) the quality of plants involved in the experiment.

(c) the amount of moisture available for each plant.

(d) the amount and quality of fertilizer used.

(e) the amount of sunlight available.

Pupils may first wish to test how the amount of sunlight

Affects two potted plants. these plants contain similar quality stock, soil, moisture, and fertilizer. One potted

Plant has a box placed over it , while the second potted plant , has access to the usual amount of sunlight

7-thinking scientifically

At selected intervals , pupils notice the effect of sunlight on plants . One variable was tested in this experiment the effect of sunlight on plants .

the experiment may be repeated Several times so that pupils observe consistency in results.. Following this experiment , all conditions must be kept constant using two similar potted plants but varying in the amount of moisture , fertilizer, and then soil.

8- Using needed reference sources .

.reference materials must relate directly to diverse units of study in science . Pupils must have available up-to-date reference sources pertaining to:

(a) Science equipment for experimentation .

(b) General encyclopedia as well as science encyclopedias

(c)filmstrips, slides, films, pictures ,video tapes, ,and study prints relating to diverse unites of study in science.

(d) cassettes, tapes , records, and radio.

(e)Library books, pamphlets, and monographs.

(f) Newspapers ,magazines ,periodicals.

(g) Maps pertaining to diverse projections .

(h)Models ,e. g. the solar system, the human body and animals (vertebrates and invertebrates).

(i) A terrarium , an aquarium, potted plants , and a place for small garden on the school ground.

(J) Diverse art media e.g. water color , colored chalk, colored pencils, and different kinds of paper for Presenting ideas.

(k) An overhead projector and transparencies , an opaque projector , and a video disc player.

Second : attitudinal goals

1. Being open ended.

2. Being curious.

3. Appreciating the methods of science.

4. Wanting to learn more about a unit of Study.

Which are selected attitudinal ends which pupils should Continually gain in school science?

1.Being open ended.

it is highly important for pupils to continually gather and weigh evidence pertaining to developing concepts ,facts , main ideas .

A closed mind generally does not desire information to modify or refute what is believed presently. individuals of this caliber do not grow in achieving relevant understanding ,skills, and attitudes. An open minded individual wishes to learn more and obtain the most accurate information possible. To develop accurately hypotheses in problem solving activities .closed mind s have a tendency to generalize on inadequate amount of information as well as to hasty conclusions.

2.Being curious.

To acquire optimal development in achieving understanding , skills and attitudinal objective In science , curiosity on the part of pupils toward the natural environment is very important .

there are numerous methods which the classroom teacher may utilize to continually arouse pupils curiosity in science:-

- Have a science center in the class setting. Pupils bring to the science center leaves of different colors ,sizes , and shapes during the early fall months. Further items to bring include an empty birds nest, acorns, chestnuts, walnuts , twigs, rocks, minerals, and insects in appropriate containers.

pupils individually or in committees may carefully inspect and discuss these items at the center. The teacher guides learners in developing facts, concepts , main ideas in greater depth or through the use of problem solving activities pupils may encourage to ask questions such as the following:

How do birds build and form their nests?

How do trees produce acorns, walnuts ,or chestnuts?

(b) Take pupils on a excursion on the school grounds or near it to observe science phenomena , pupils may observe during fall months diverse kinds of birds ,trees, grass, flowers, clouds , and changes in weather. Pupils feel free to discuss observation s made as well as identify new problems .

3.Appreciating the methods of science

- .too frequently Pupils do not appreciate the opportunities to identify Problems or gather relevant information for solving of Problems . Further weaknesses pertaining to pupils Thinking deal with inadequate hypotheses developed as well as inferior methods of testing these hypotheses.

- . Learner too frequently want to jump to hasty conclusions when gathering information to solve problems. when pupils engage in problem –solving Activities , each flexible step in this method must receive Its share of attention. When pupils gathering related data to solve problem s, the pupils must critically and creatively appraise acquired content ,

Which approaches in teaching –learning situations may help pupils to appreciate the methods of science as a mean of acquiring relevant content?

- (a)Provide *a stimulating learning environment* which guide pupils to identify problems of very own choosing

Rather than the teacher determining specific questions for pupils to answer.

- (b) Explain to pupils *why scientific thinking is important*
- .guide pupils in using critical and creative thinking when appraising content related to problems.
- (c) have *material available for use by pupils* which stimulate curiosity in learning

4- wanting to learn more about a unit of study .

satisfactory methods should be utilized to:-

(a) Introduce a new science unite. With these initiate

Activities , pupils should develop interest, sense of purpose , and receive meaning in learning acquired .

(b)Develop *learning in greater depth* within pupils.

Developmental learning experiences should help pupils to perceive interest, purpose and meaning as well as develop concepts ,facts and main ideas in *greater depth* as compared to initiating activities.

(c)End a unit. Culminating activities should draw a unit of study to successful conclusion.

What destroys pupils interest in desiring to learn new content in science?

(a) Excessive emphasis placed on reading as a mean of acquiring information.

(b) The same methods and materials used in teaching science .

(c) too much stress placed upon rote learning and memorization of content.

(d) All pupils in the class setting participating in the same learning activities at the same time.

(e) The teacher require pupils to give “right” answers to questions rather than more open –ended approaches to

Teaching and learning.

(f) The teacher determining objectives, learning activities and evaluating procedure for pupils.

5- appreciating the contribution of science which has helped improved conditions of living for human being on the plant earth in the following ways:-

(a) Increasing the *life span* of human being .

(b) Having *modern conveniences in the home* such as

Centralized heating and air condition , automatic closes washers and driers, refrigerators, and electric lights.

(c) experience *fast and efficient means of transportation* e. ,g. jet plane, car, bus and train.

(d) Increasing *production of farm crops* and *livestock* on farm to provide a more adequate supply of food product .

(f) Experiencing *increased production of goods and* services in the economy .

In a unit entitled " our earth and its surface" pupils may achieve the following understanding objectives :-

(a) Approximately seventy per cent of the earth s surface is covered by oceans , rivers , lakes .

(b) Mountains change in shape as they mature in age.

(c) the earth continually undergoes change , such as the occurrence of earthnuts, volcanic eruptions, erosion

(d)The study of the oceans has become increasingly important to human being . Oceans will provide a greater supply of food, water, and minerals to human being in the future.

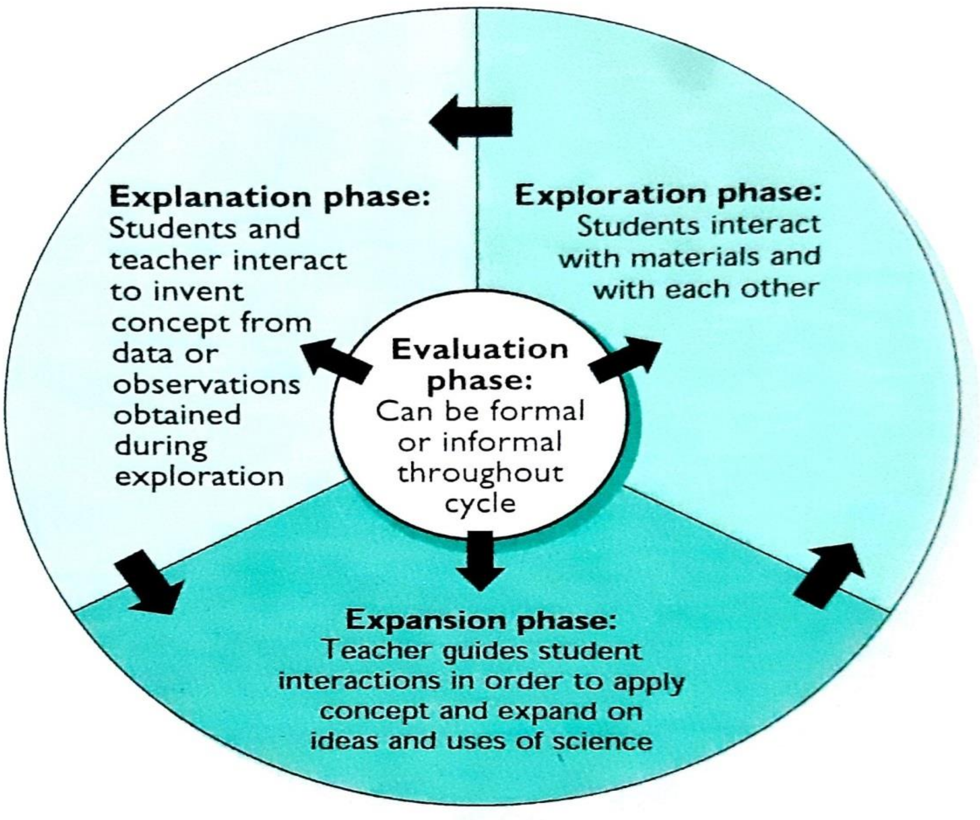
(e) The breaking of rock ultimately makes for topsoil.

(f) One or more kinds of minerals comprise a rock.

(4) :The science learning cycle

In science , a learning cycle is a way *of thinking* and *acting* that is consistent with how pupils learns. It provides an excellent approach *for planning* effective science instruction .

The science learning cycle originally consisted of three phases :(exploration , concept invention ,and application) . With today `s goals emphasizing new dimension of science and accountability, we recommended a 4 –E learning cycle :(exploration, explanation, expansion , and application) .



Phase one : Exploration

1.The *exploration phase* is student centered , *stimulates*

Learner *mental disequilibrium* , and *foster* mental

Assimilation . The teacher is responsible for divining student *sufficient directions* and materials that interact In ways that are related to the concept.

2.The teachers *directions* must not tell students what they should learn and must not explain the concept . The teacher `s role is to:-

* Answer students questions.

* Ask questions to guide student observations and to cause students to engage in science processes or thinking skills.

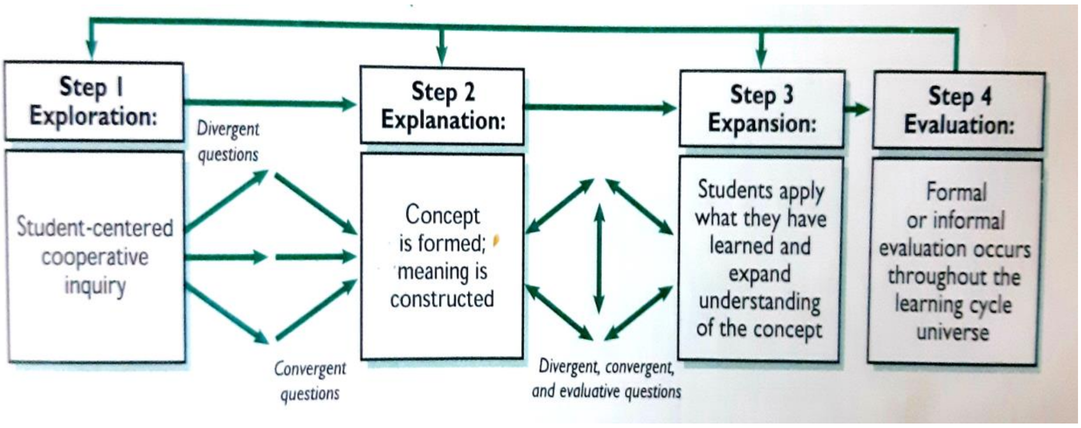
* Give hints to keep the exploration going .

Students are responsible for exploring *the materials and for* gathering and recording *their own information . Teacher rely on questioning skills such as those shown in the following figure .Students must* *have concrete material* *and experiences Too if they are construct science concepts for themselves . Use* these guiding questions *to begin Your planning process*

** What is the precise concept the student will explore?*

**what activities must the student do to become familiar*

With the concept?



* What kind of observation or records should student keep?

* What kind of instructions will the student need ?

- How can I give the instructions without telling the concept?

Phase two Explanation

The explanation phase is less student centered and *provides* for learner *mental accommodation* . The purpose of this phase is for teachers *to guide* student thinking so the concept of the lesson is constructed Cooperatively , not merely given by the teacher.

To accomplish this , the teacher *select* and sets the desired *Classroom environment* . The teacher asks student to give the *information they* have collected and Help the student to *process and mentally organize the Information Once the information is organized* , the teacher introduces The specific language needed for the concept .Much as teacher did after his student had observed and explored what happened when a new organism was introduced into their terrariums. Teachers help students to *construct and attach meaning* to these new words- the concept.This phase helps to lead to mental accommodation ,here students must focus on their primary findings

From firsthand explorations .the teacher must introduce

Language or *concept labels* to assist mental accommodation.

These questions can help teachers guide students so

They *construct their own explanations* of the concept:

* What kind of information or findings should the student talk about?

*how can I help students summarize their findings?

* How can I guide the students and refrain from telling

them what they should have found , even if their

understanding is incomplete? How can I help them use their

information to construct the concept correctly

* what labels or descriptions should the students attach to the

concept?

*what reasons can I give the students if they ask me why the concept

is important? This question lead to the next phase.

Phase three: Expansion

The expansion phase should be student centered as much as possible and organized to encourage group cooperation . The purpose of this phase is to help learners mentality *organize the experience* they have acquired by forming connection with similar previous

Experiences and by discovering new application for what they have learned .constructed concepts must be linked to other related ideas or experiences . The purpose is to take the *students thinking beyond where* it is presently . You must require students to *use the language or labels* of he new concept so that they add Depth to their understanding.This is a proper place to help *students apply what* they Learned by expanding examples or by providing additional *exploration experience*s for stimulating student s science inquiry skills . Encouraging them to Investigate(science – technology – society) interrelationships , and for understanding the history And nature of science.

The expansion phase can lead to the exploration phase of the next lesson. Teachers help students *organize their* thinking by *relating what* they have learned to other ideas or experiences that relate to the constructed concept.it is very important to use the language of the concept during this phase to add depth to the concepts meaning and to expand the range of learner vocabulary .

Consider these questions:-

*what previous experiences have the student had that relate to the concept?

*how can I relate the concept to those experiences ?

- *What are some example of how the concept encourages the students to see science s benefits to themselves ? To help them understand the relationship among science, technology, and society? To help them develop science inquiry skills ? To help them to informed about the history and nature of science?
- * What questions can I ask to encourage students to discover the concept s importance? To apply the concept? To appreciate the problem

it solves? To understand the problem it causes? To identify the careers influenced by it? To understand how the concept has been viewed or used throughout history?

- * What new experiences are needed to apply or expand the concept?
- *what is the new concept related to present one ?how can I encourage exploration of the next concept ?

Phase four : Evaluation

The purpose of this phase is to *overcome the limits* ofStandard types of testing. *Learning* often occurs in small increments before larger mental leaps of insight are possible .therefore, evaluation should be continuous , not a typical end – of chapter or – unite approach .

Several types of measures are necessary to Form a holistic evaluation of the students ` learning and to encourage mental construction of concepts and process skills . Evaluation can be *included in each phase*

Of the learning cycle, not just hold for the end Ask yourself:

* What appropriate learning outcomes should I expect?

* What types of hands-on evaluation techniques can the student do to demonstrate the basic skills of observation , classification , communication , measurement , prediction , and inference?

*what techniques are appropriate for students to demonstrate the integrated science process skills of identifying and controlling variables , defining operationally ,forming hypothesis , experimenting , interpreting data ,and forming models ?

* How can I use pictures to help students demonstrate how will they can think through problems that require understanding fundamental concepts and the integration of ideas?

* What types of questions can I ask students to help them reflect

How well they recall and understand what has been learned?

What goals promote scientific literacy

CHAPTER TWO

5- What is scientific literacy.
6- Diversity in classroom.
7- The problem of Discipline.

(5) : What is scientific literacy?

(1) A literate person has a fundamental command of The essentials: what one need to know and be able to do in order to function as a contributing member of Society.

(2) Scientific literacy means that a person can ask and find or determine answers to questions derived from curiosity about every day experiences it means the ability to describe ,explain, and predict the natural phenomena. A literate citizen should be able to evaluate the quality of scientific information on the basis sources and methods used to generate it.

(3) Very broadly ,then, a scientifically literate person has a capacity to use essential scientific attitudes ,processes ,and reasoning skills and science type of information to reach reasoned conclusions and use the ideas of science in meaningful ways. In other words , educators are encouraged to believe that if they teach a persons how to learn , the person will learn for a lifetime” teach a person how to fish , feed the person for lifetime” goals promoting scientific literacy

Dimension 1.Science as inquiry :

Inquiry means the use of the processes of science .scientific knowledge , and attitudes to reason and think critically .inquiry assists in constructing an understanding of scientific concepts ,learning how to learn ,becoming independent and a life long learner and further developing the habits of mind associated .with science The student will:

1.1 develop abilities necessary to do scientific inquiry .

Science as inquiry

- Ask questions about objects, organisms ,and events .

-plan and conduct simple science investigations.

-use simple science tools in order to gather, analysis and interpret data.

-use data to construct descriptions ,explanations ,predictions, and model.

-identify relationships between evidence and explanations.

- Communicate ,critique ,and analyze the work of others.

1.2 understand about scientific inquiry.

* Ask and answer questions and compare answers to what scientists already know about the world.

* Select the kind of investigation that fits the question

They are trying to answer.

* Realize the instrument provide more information than a scientist can obtain only by using his senses and enhance the accuracy of that information.

* Develop explanations that are based on observation ,evidence , and scientific concepts.

*describe investigations in ways that make it possible for others to repeat it.

* Ask questions about the results of others works.

Dimention2. science and technology

2.1 develop an ability to distinguish between natural Objects and the objects mad by human.

* Realize that some objects occur in nature and that others have been designed by people to solve problem.

* Categorize objects into two groups , natural and designed.

2.2 develop an ability to understand and produce a technological design.

*identify an age-appropriate problem for technological

Design, propose a solution , and design it.

* Evaluate a product or design and communicate the results

To others by describing the process of technological design.

2.3 understand about science and technology.

*realize the science and technological design often have similarities and differences that make it necessary

For scientists and engineers to work together, in order to solve problems.

* Understand that science and technology provide opportunities to women and men of all ages , background, and abilities to do various scientific and technological work.

* Understand that tools helps scientists to make better observation measurements and that science drive technology

—*Understand that people have always had questions about the natural world and that scientists have invented tools and techniques to help answer those questions.

* Understand that technological designs have constrains and that technological solution may have intended benefits and unintended consequences , some of which may not predictable.

dimension3. science in personal and social perspectives standard

<u>3.1 develop an understanding of personal health.</u>

* Understand that safety and security are basic needs of humans.

* Demonstrate responsibility for their own health through regular exercise routines.

* Understand that good nutrition is essential to health,, develop nutritious habits , and recognize that nutritional needs vary with age, sex, weight, ,activity . And body functions.

* Recognize and avoid substances that can damage the human body , including environmental hazards (e.g. lead, radon), and recognize that prescription drugs can beneficial if taken as directed

* Recognize the potential for accidents , identify safety

Hazards , and take precautions for save living.

* Understand the consequences of new life and disease.

<u>3.2 identify characteristic and describe change in population.</u>

* Understand that human populations include groups of persons who live in a particular location.

*understand that density refers to the number of individual of population who can live in a particular amount of space.

*realize that the size of human and animal population can increase or decrease unless factors such as disease, insufficient foods ,or disasters limit it ,overpopulation increases the consumption of resources.

3.3 Identify types of resources.

* Understand resources are materials we get from the living and nonliving environment to meet the needs of a population.

* Identify examples of resources such as air ,water ,soil, food, building material and the nonmaterial such as quite places, beauty ,security and safety.

*under stand that the supply of resources is limited butThat recycling and reduced use can extend the length of time that resources are available , over consumption and over population deplete resources.

3.4 identify environment and change

*understand that the concept of environment includes The space, conditions ,and factors that effect an individual s quality of life .

* Realize that environmental changes can be caused by Natural or human causes .

*understand that internal and external changes in the earth s system cause hazards and destruction of life.

*understand that population is a change in the environment that can influence health.

*comprehend that some environmental changes occur slowly and others rapidly and describe examples (weather, climate, erosion , movement of large geologic mass.

3.5 recognize the benefits and challenges of science and technology.

*understand that invention and problem solutions can effect others people in helpful and harmful ways.

*recognize that science influences society through its knowledge and that technology influence society through its products and processes.

*identify risks and analyze the potential benefits and consequences and understand that risks and benefits

Relate directly to personal and social decisions.

*understand that science can not answer all questions and that technology can not solve all human problems.

Dimension 4.history and nature of science standard.

4.1 understand that science is a human endeavor.

*realize that science and technology have been used for a long time.

*understand that women and men have made important contributions to science and technology through history.

* Understand that there is still much to learn about science

*understand that doing science requires persons of different abilities and talents.

4.3 understand the nature of science

* Realize that scientists use consistent procedures

To test explanations and to form ideas.

- Understand that scientists do not always agree
- Particularly when active research is pursued in new experimental areas , but that science ideas

Are supported by considerable observation and Confirmation

4.3 understand the importance of history to science.

- Realize that studying the lives and times of important scientists provides further understanding about the nature of scientific inquiry And the relationships between science and society.
- *realize that the history of science reveal that

The scientists and end engineers of high achievements are considered to be among the

Most valued contributors of any culture

(6) :Diversity in classroom

1. What different learning styles can you expect in your classroom ? How do you plan lessons to address the needs the needs of
2. students with these learning styles?

2. What is the theory of multiple intelligences , and how do you apply the theory in lesson planning?

3. How do you modify science instruction to include students with learning disabilities?

4. How do you address the needs og gifted students in your classroom?

What different learning styles can you expect in your classroom ? How do you plan lessons to address the needs the needs of students with these learning styles

Learning styles :Learning styles refers to the traits that learner exhibit

In the classroom . These traits tell teacher something about how students match the preferred way in which A student learns new content and skills.

Learning styles models:

Several learning styles models exist that suggest teaching strategies to match student s learning styles..

(1) Dunn and Dunn Approach.

They identify four important variables pertaining to student s cognitive , affective ,and psychological traits Dunn and Dunn s Approach

a. The learning environment ,(b) emotional support

(c) Preferred amount of peer interaction , and (d) personal and physical traits.

a. Think about the learning environment that you prefer what is it like? Is it quiet room ? Is it a well lit or dimly lit room? Do you prefer to sit in a cer*tain place in the* classroom?

(b) How much emotional support do you require , and what type? Do you need help getting motivated? Are You persistent ? Do you take on responsibility or prefer to have others take the lead?

(c) What about peer interaction ? Do you work individually ,with a teammate , or in a group? When you were younger , did you prefer to learn from an adult ? do you prefer to work alone at times and with others at other times?

(d) What are your personal physical traits and your basic modalities ? Are you an auditory learner who like to hear things , a tactile learner who prefer prefers touch ,a visual learner who likes to see things or do you prefer movement?

Variables influencing learning style

<u>Learning environment:</u>

- Quiet/ noisy - a particular location

- Brightly lit / dimly lit

<u>Emotional support :</u>

- self-motivated / needs motivation

- Takes the leads / follows others.

<u>Preferred amount of peer interaction:</u>

-works alone / likes a learning partner

- Likes group learning

<u>personal and physical traits :</u>

-auditory learner

- Tactile learner

-kinesthetic learner

-visual learner

- Achievement motivated

- Socially motivated

<u>Activity : using gregoric learning style to teach about the sense of smell.</u>

<u>Material</u>: five empty film container with leds, cotton balls ,vanilla extract ,lemon juice , cologne , vinegar , bits of chocolate.

<u>Procedure</u>: introduce the sense of smell to his students

In four different ways , each one taking advantage of Gregoric s research on learning styles when you are in the field , you can try in in your college classroom observe your college at work , <u>what do learn from their behavior?</u>

1. Each of four film containers holds a cotton ball soaked with different scent . The first is soaked with vanilla , the second with lemon , the third with cologn , and the fourth with vinegar,

<u>Activity2 : using gregoric learning style to teach about the sense of smell.</u>

<u>Material</u>: five empty film container with lids , cotton balls ,vanilla extract ,lemon juice , cologne , vinegar , bits of chocolate.

<u>Procedure</u>: introduce the sense of smell to his students In four different ways , each one taking advantage of Gregoric s research on learning styles when you are in the field , you can try in in your college classroom observe your college at work , <u>what do learn from their behavior</u>?

1. Each of four film containers holds a cotton ball soaked with different scent . The first is soaked with vanilla , the second with lemon , the third with cologne , and the fourth with vinegar,

The fifth container holds small bits of chocolate , students smell the contents of each container . Remember this safety consideration : when smelling something , student should hold the substance an arms Length away and wave their hand past the opening of The container bringing the odor toward the nose,. never Put the substance directly beneath the nose and breath in, if the substance is harmful an injury will result . Find out if your students are allergic to any of these substances before including them in the activity . Send a note home to parents To find out about allergies.

2.Set up four stations and present the lesson in four different ways . Describe the station to your students and let them choose the one they like best . Observe the way they response to each station .

a. <u>for concrete- sequential</u> learner who like many Concrete example presented in an organized fashion ,provide the prepared film canisters for them to smell

Give them a chart to fill out so they can describe the odors on a response sheet in an organized fashion.

b. For concrete –random learns , present the prepared Film canisters tell them they will experiment with the canisters and investigate which odors they like best and which they like least.

c. For abstract –random learners , set up a cooperative

Problem solving session . Ask them to design an experiment to learn about the sense of smell .

d. For abstract – sequential , form a discussion group. Have student come up with series of rules to follow when smelling an unknown substance in a film canister Then have them create a response sheet to describe and Categorize the odors

McCarthy `s teaching model

McCarthy `s method based on the work of Kolb& Jung Who studded who learner perceive and process information she defined four types of learner based on how they perceive and process information:

1.Imaginative learner : who perceive information concretely and process it reflectively . Prefer sensing ,feeling and watching

2. Analytic learner: who perceive information abstractly and process it reflectively . prefer thinking and watching

3. Common sense learner: who perceive information Abstractly and process it actively. Prefer thinking and doing

4. Dynamic learner : who perceive information concretely And process it active. Prefer sensing felling ,and doing.

Example(1) :

The first phase: the teacher organizes a situation that make reason for about a concept or topic.in effect ,Motivation answer the question " why would I learn this? "For example , for a lesson about the human skeletal system.

Student might be asked to select a bone or set up of bones And describe their function

the second phase: the teacher develops the concept with students. This could be in a lecture format ,using Direct instruction or in small study groups. this phase focuses o teaching content and answers the questions

"what do I have to learn?"

The third phase: involves application of concept, student might engage in drill and practice of concepts developed in the second phase . In the science classroom they might engage in inquiry ,setting up an experiment to learn more about the topic . This phase Focuses on answering the question" how does this work ?"

The fourth phase: students evaluate and refine their ideas . They might make real –world connections , answering the question " how can I apply this information? "using the principals earned ,they might

Study the bones and muscles in in the hand and think about how they work together to enable us to hold things and write . In what other ways can you apply Principles of anatomy and physiology with students?

McCarthy`s Model of teaching:

Phase 1.why should I learn this? Phase 2.what will I do?Phase3. how does this work? Phase4. how can apply this information?

Example 2.applying McCarthy `s model in teaching science

Material; music with elephant sounds , videos of elephants , paper and marker for drawing , worksheet on elephants for drill and practice , maps of where elephant live.

Procedure: imaginative learners : being the lesson by motivating imaginative learner. student listen to tapes of elephant sounds and move around the room, pretending they are elephants .they use very large

Construction paper to make a life-size picture of an elephant they compare their own sizes with that of an elephant . They Create stories about elephants and read books about them.

Analytic learners: the lesson continues as students watch content-rich video about elephants. You might teach about

To the whole class .this phase of the lesson develops the content.

Common sense learners: students being to apply what they learn. They locate area of the world where elephant live and make maps of those areas . They may complete worksheets to practice and review the lesson.

Dynamic learners :these learners like action. As instruction continuous , student can select work on

Elephants for their portfolios, create a gallery of elephants art in the hallway , writes stories about elephant or read stories to parents.

(7):The Problem of discipline

= introduction.

=Reasons for not using outdated

approaches.

=Don’ts in disciplining pupils.

=Ways to improve pupils behavior.

=In summary.

Introduction:

Not much is written about the problem of discipline. One reason for this , perhaps, deal with:- a. the fact that children differ from each other in many ways and approaches to disciplining one pupil may of course , not work with another pupil.

B . Another reason may be that the word discipline has a negative connotation. Also teachers perceive things differently when identifying a pupil as being a discipline problem.

Reasons for not using outdated approaches.

The following reasons would be *given for not using outdated approaches :-*

1- pupils are not helped in emotional development since positive attitudes cannot be developed when pupils are negatively affected by physical punishment.

2- learners cannot develop well socially if pupils are isolated from other children when negative approaches

To disciplining are being used. Good teaching would help Learners to be accepted by others.

3- it is very difficult for pupils to develop adequate self concepts when being threatened by physical punishments.

4- minimizing human beings is not in harmony with basic idea relating to democracy as a way of life .democratic living stresses the importance Of human beings respecting each other.

5- if pupils are to become contributing members in a democratic society , they must develop positive attitude towards others, school , and others

6-the teacher serves as a model to pupils in the of area democratic living. The teacher classroom teacher is a very important person in learning environment.

7- pupils should have a voice in determining standard of conduct for learner to follow.

8-the teacher should evaluate his own teaching to determine if discipline problems arise because of faulty objectives, learning activities , or evaluation techniques.

Don’ts in disciplining pupils.

Teachers , principals, supervisors, as well as writers in the field of education emphasize the following don'ts pertaining to disciplining pupils:-

1- do not use subject-matter to punish children. For example do not a child work page 57 in his mathematic textbook for a misdeed. If this is done he may associate punishment with mathematic, 2- do not scold pupils for their shortcoming in front of other children, if this is done ,the child being reprimanded has a tendency to be isolated from friends and peers.

3- do not have students stay in during play period for misbehaving. Pupils need variety in learning activities , and play makes for definite change in daily routine, learners need ample opportunities to engage in physical exercise in addition to those learning activities which require little or no physical movement.

4- do not use physical punishment since is not human and better approaches are available to change

Behavior.

5- do not use approaches in disciplining pupils which tend to minimize children.

there are many things the teacher can try in attempting to improve negative behavior of pupils in school setting , among these ways would be the following :-

Ways to improve pupils behavior.

1- learn as much as possible about the home of the pupil .if there is illness in the home , this will definitely affect a child s behavior. Abnormal disagreement and rivalry among children in a home will also affect a given child behavior in school. Thus teacher needs to learn much about the home situation and try to understand the child from his very own point of view

2-the teacher should evaluated his own teaching. A textbook centered approach does not provide for enough children. For some learner, the textbook is too difficult to children, for others it is too easy ,in other cases the textbook is not the most interesting material to use in teaching. Discipline problems arise when approaches to teaching need to be modified .

3- a few teachers expect pupils to be passive individuals Their thinking is that children need to sit very quietly at their desks in order for learning take place. they do not recognize that pupils should be actively involved in ongoing activities

4-When pupils in a committees engage in conducting and discussing science experiments ,there will be some noise in the class . Learners in committee sharing ideas obtained from using a variety of reference sources can not do this in a quit classroom environment where one could hear a pin fall to the floor.

5- the teacher should not confuse creativity . Some teacher have scolded pupils who ask many questions and do not like prescribed ways of doing things .these learners may also have been scolded for not giving exact answers to questions in words as needed as answer. thus teachers must give opportunity to creative children to be playful with ideas.

6-the teachers should use praise freely for those who are meeting proper standard of behavior. There are teachers who are afraid of to praise positive behavior they feel that pupil will misbehave .the teacher must use praise as follow:-

- a- the teacher can use the words”

  that’s good” excellent” ,”tremendous”,

  ”very good”,” that’s dandy”

b-the teacher can use nonverbal communication:-

- a smile by teacher
- a positive nod of the head by the teacher’

7- reasonable standards of conduct should be developed cooperatively between teacher and learners.

A- example for a teacher using standard:

Pupils entering a new class for the first time do not know what is expected of them in term of standard of conduct . There are first grade teachers who have a permissive learning environment.

They permit pupils to:-

- talk freely with each other during learning activity'
- get material from different places in the classroom.
- move sequentially from one center of learning to another center as their own choosing.
- teacher serves as a consultant or helper to pupils.

B- pupils leaving this class setting and moving to a second grade room in the next year.

They experience the following:-

a)Pupils sit in straight rows.

b)No one can get up from their desks without permission from the teacher.

c) There is no committee work.

d) Pupils are learning largely from the use of textbook , workbooks and duplicated material.

e) The teacher does much lecturing and explaining.

f) There is basically no noise in the room.

g)A rigid time schedule is followed in teaching pupils.

h)Pupils line up to come into the room and to leave the the classroom.

i)Exact one, two, three, word answers are given

to questions asked them by the teacher.

J) The teacher is very formal in teaching subject-matter to pupils.

k) Children basically are not praised for improved efforts and work.

l)The teacher is a very rigid individual expecting

Learner to complete all textbooks ,workbooks ,in Allotted time.

Conclusion:-

It is necessary to discuss with pupils standard of conduct that will permit a good learning environment .democratic living emphasizes that pupils be actively involved in developing these standard with teacher guidance.

7- a common cause of misbehavior in the class occurs when the teacher uses too much lecture. It is for pupils to refrain from listening in situation such as this.

During the time of lecture ,it is difficulty for the teacher to know if learners are comprehending.

The teacher must observe pupil behavior carefully when teaching .if pupils appear to be board or they have turned off, the teacher can change the kind of learning activity.

CHAPER THREE

8-The design loop.

9-Practical suggestion for working

With special needs in the regular classroom.

10-Important summative assessment.

(8) :The design loop

introduction

Technology is a tool developed to accomplish a

Purpose . Design and technology go hand in hand . Design is the planned process of change .

Designing helps you to plan changes so that you end up with the desired results . minimizing trade-offs and controlling risk

The design loop is a problem solving strategies

Design enables you to develop solutions to a careful planned way. Is there a problems in particular way to do this ? Technologist use the design loop to make problem solving effective . It is an active process that enables you to define a problem and specify in details the requirements of the solutions . You then do research and investigate the information you need to help solve generate a the problem. Once that is done , you number of possible solutions . After careful

Thought and discussion . You choose what you determine to be the best solution

Then you do the developmental work needed to build a model. You construct test and evaluate the model .

=when your students use the design loop , they learn that there is no perfect design a design that is excellent in one respect, such as appearance or ability to do the job , may cost too much to produce . Even the best design can fail . You can work hard to reduce the likelihood of failure .

Steps of design loop

Students in the middle grade should learn that they must take constrains and limitation into account when designing .

a. Antibiotics are important for controlling disease but they often have harmful side effects ,b. spray can are useful in dispensing aerosols such as hair spray , cooking oils or paint but in the past they damaged the ozone layer. Today we have spray cans that do not harm the environment

Student should know that sometimes an idea needs more research and testing before a system is designed . The limitation and constrains need carful consideration . You should discuss these issues with your students when engaging in design and problem solving.

1- Identifying the problem

You will now learn about design loop challenge .

Challenge is a meaningful problem that you solve by using the design loop . Design challenge

Often require a technological solution .suitable design tasks for students should be well-defined. So that the purpose of the task are not confusing . Tasks should be based on context that are that are immediately familiar to the(homes ,schools , and community)of the students. The first step in the design loop is to identify the problem and think about it carefully ..

Here is a design loop challenge that result from

The needs for children to eat healthy foods . It is one that you can try to in your college classroom .children should eat nourishing meals , but they often do not .they skip meals or eat junk foods . List five ways in which eating habits of children could be improved .

2- creating a design brief

After you identify possible problems by listing five ways to improve the eating habits of children . You specify one that you will solve . The next step is to create a design brief . The design brief clarifies the problem and describes the task here is an example .

Create a new sandwich that includes foods that are nutritious . Make the sandwich colorful and appealing to elementary school children

A design brief is similar to a performance task it is a statement of the problem to solve and the criteria to meet . Notice how the design brief is structured . Students must create a new type of sandwich and include foods that are nutritious

. You do not tell them to study about foods that are nutritious . They figure this out for themselves and then learn on their own. Criteria for success and the constrains for design should be limited for students

3- Gathering information

Now the problem is specified . The next step is for students to do their research . They will learn about food groups , about taste and about color

They have a reason for learning because they

will apply that knowledge in the design process

4-Generating alternative solutions

In this step , students apply their research as they design many different sandwiches. (

(Ideas solutions) they brainstorm different

they decide which ones are unworkable and which ones make sense. They decide on criteria for selecting the best design . Criteria might be number of foods in the sandwich , chew ability , visual appeal , and nutritional value . Notice that although certain criteria were specified in the original design brief ., in this step students refine

And expand the criteria . As they gain more knowledge about the problem and consider constrains and limitations . They assign their own criteria to the solution

5-Choosing the best solution

In this step , students apply the criteria in the design and decide which ones meet them and which ones do not . Some sandwiches may contain too many different foods , some may be difficult to chew , some may not be visually appealing ,and some may not be nutritious. Students consider benefits and trade-offs as they work

6-Doing the developmental work to plan for construction

Now your students are ready to do the technical

Planning before they construct the sandwich . They sketch the sandwich and decide what needs to be done to make it work. In this case of

the sandwich , there is a little developmental work to be done . More complicated designs require developmental work and planning .think about the problems associated with the river with overflowing its banks . Much more developed work is required in planning for construction of devices that will control the water level

7- Making a model

Your students are finally ready to make a model of this sandwich . They can do this in many ways . Using the computer with program such as kids pix. they can draw a model of sandwich .they can use different color play dough or colored clay to build an appearance model to show what the sandwich will look like . Then they can make the actual sandwich.

8-Testing and evaluating the model

Now the sandwich exists , your students can test and evaluate it .does it meet the specifications set forth in the design brief ?does it include foods that are nutritious ? Is the sandwich colorful and appealing to children? After evaluating the model your students might like to go back and test another solution

(9) :practical suggestions for working with students with special needs in the regular classroom

1-access to content

When a special education student enters the science class , you must first determine how that Child best accesses the content. Can he listen and comprehend ?can he read and comprehend.

Is it best to tape records directions and explanations ? would the student benefit from a side –by – side reading situation in which he works with a peer ? Next you determine the amount of content the student can handle.

2- Support

The student of special needs often require support. Assess student , confer with her and decide whether she will work alone, side by side with a partner , or in a group , this configuration may change from time to time depending on the activity .

As the year progresses the special need student may require less support they may also find that she fits into the regular classroom more easily .

3-Set evaluation expectations

Just as you do with student in the regular classroom scoring system confer with the student with special needs and set evaluation expectations if you use performance assessment explain the performance task response sheet , scoring system to the student . Let the student know how you will assess him.

4-Differentiated learning

With learners of different abilities , you will need to adapt lessons in various ways . First determine how much repetition your special need student require to learn the material ,Second find out how much work they can handle, how much Time they need to complete an assignment and how they access the content

5-When a student is stuck.

Sometimes special needs students are stuck ,they are not understand , and they have not

Strategies that will help , you can set up learning centers around the room to help them access to

Content. Chapters on tape , reading assignment

, and computers with proper software or access

to the internet help to move them toward. Being aware of their learning strategies also help.

6-If student being to get out of control

Special needs students sometimes exhibit aggressive behavior and are difficult of control ,

Perhaps the most important results toward including special needs students in regular education classroom improved following our intervention .we developed ways to help new teacher maintain control of the classroom in difficult situation

7-If student being to get out of control

Here is one technique that works.

Every teacher needs a stop signal . You can hold up your hand or simply tell students to stop in a firm voice. you can ask them to close their eyes . Ask every one to remain silent for few seconds tell them what you want to do then go on . If a particular student causes a problem, schedule on minute conference, write unsolicited letters of reference for student who are doing a good job to

Reinforce good behavior, for some pupils behavior

Is a definite problem if you establish the rules at the start

And adhere to them consistently , you can expect to have

Fewer problems .

8-Working with a short attention span

If a student has a short attention span, shorten the task that you assign . Give less homework , you will find that engaging of science lessons that Encourage thinking and group work often

Solve the problem of the short attention span.

9-Handling distractors

Some students are easily distracted . This can be

dangerous when engaging in science activities .

Seat such student near you and surround them with quite students . Scan the room for distractors , and keep them as far away from the students as possible . Give simple directions . We found that some distractible students were easier to handle when kept busy.it often help to cover their desks with a large sheet of paper and allow them to doodle as they listen and work

9- Ending the science activity

Students with learning disabilities often enjoy

Hands- on science . They may have difficulty

Transitioning from science activity to another , let Them know that the science activity will finish and another activity will begin . Provide time for Transition .allow them to unwind before moving on

10-When a student refuse to work in a group

Some student with learning disabilities may refuse to work in a group because un successful

Prior experiences. Find one other student who

Can work with the child . Allow the pair to explore together . Then add another student to the group . Gradually build the student `s confidence and social skills.

11-I may be paying attention even if I look I am not

Many students of learning disabilities need extra time to process . they often look like they are bored , not paying attention or spacing out .

This Is especially true in inquiry based science lesson, which require lots of thought . Meri shared a story of a teacher who constantly reprimanded her and called her lazy because she had a blank star on her face. We learned by working with Meri that the look was one of deep thought . Not boredom or lack of attention . When extra wait –time an excellent answer resulted.it just took a little longer than we thought it would. Be patient and do not be Judgmental

12- listening skills

Be sure the child comprehends what she is hearing .have the child repeat what he hearing

.she may hear but not understand. This is something you should assess regularly

13-Organizing work

Organizing work is the number one priority for

Many science teachers . Students are often

Unprepared , lose important papers , forget their books , and do not follow directions

several years, I conducted research on how Elementary science students follow directions .

Observed 84 lesson in one year and found that

When the teacher began to give directions about 50%percent of the students stopped listening

14-Working with science equipment

Working with science equipment can bring challenges you never considered .when working

With Meri , we learned that many of activities we thought were appropriate for all students were difficult for a student with an orthopedic

Handicap.

Assess your activities for developmental appropriateness as well as psychomotor readiness ,some students may have an immature grasp or an inability to manipulate equipment .you may not be

Able to predict all difficulties , but you will detect

Them as the lesson proceeds . Make substitutions the next

Time around.

15-Classroom rules , especially for safety

As with all of your students be sure Your special needs students follow all safety rules at the start

Of the year .develop a list of safety rules together post them in the room . Before each

.have Activity make it a point to talk about safety your special needs students repeat the rules aloud .if an activity is likely Formative assessment appear to have been one of the most neglected areas of classroom practice, and has always been the poor relation to the

(10):Important summative assessment:

Formative assessment(or assessment for learning)is simply giving feedback to pupils that will support and assist them in their learning of science.it goes beyond telling pupils that they got this or that wrong to telling them why they have got it wrong and how they could get it right next time round. .

o pose some Danger if it not carried out properly , and if you believe directions would not followed . Think of ways of substitute another activity

What is formative assessment?

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There are five assessment that lead to ,learning these are:- improved

1-The provision of effective feedback to pupils.

2.the active involvement of pupils in their own

Learning

3.Adjusting teaching to take account of results of ass.

4.A recognition of the profound influence assessment has on the motivation and self esteem of

Both of which are crucial influences on learning

5.The need for pupils to assess themselves and understand how to improve

The value of formative assessment

There is strong evidence to suggest that good

Use of formative assessment will:-

Lead to improved results in examination.

Help raise the standards of the low- attainders more than the rest , reducing the spread of attainment.

Wake – up those pupils who are getting by the minimum of work and simply cruising along.

help to highlight those things that are important to learn.

Helps pupils learn how to learn(by influencing the choice of learning strategies , by inculcating self-m0nitoring skills , by developing the ability to

retained apply knowledge , skills and understanding in different context.

Help pupils to learn how to judge the effectiveness of their learning .

-Promote deep rather than shallow learning

-raise pupils `self-esteem and improve attitude toward learning

Formative assessment is being used in schools today ,teachers are constantly giving feedback to pupils .as they go round the classroom they listening to what pupils say pupils

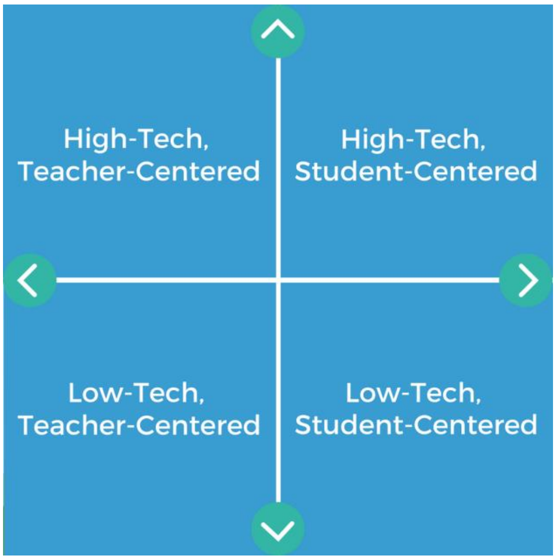
Have not understand properly, they correct things

CHAPTER FOUR

11-Teaching methods.

12-Teaching the science of learning

(11)Teaching Methods



The term teaching method refers to the general principles, pedagogy and management strategies used for classroom instruction.

Your choice of teaching method depends on what fits you — your educational philosophy, classroom demographic, subject area(s) and school mission statement.

Teaching theories can be organized into four categories based on two major parameters: a teacher-centered approach versus a student-centered approach, and high-tech material use versus low-tech material use.

Interested in developing your skills as a teacher? Explore online education short courses designed to give you an in depth understanding of various skills in teaching.

Teacher-Centered Approach to Learning

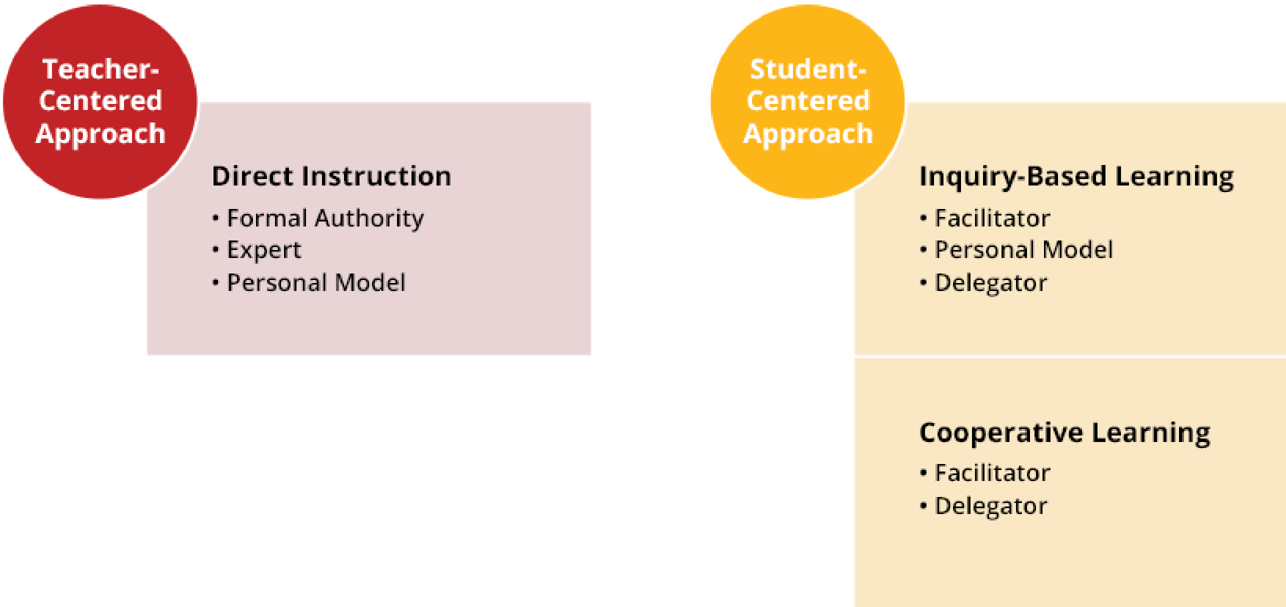
Taken to its most extreme interpretation, teachers are the main authority figure in a teacher-centered instruction model. Students are viewed as "empty vessels" External link who passively receive knowledge from their teachers through lectures and direct instruction, with an end goal of positive results from testing and assessment. In this style, teaching and assessment are viewed as two separate entities; student learning is measured through objectively scored tests and assessments.

Student-Centered Approach to Learning

While teachers are still an authority figure in a student-centered teaching model, teachers and students play an equally active role in the learning process.

The teacher's primary role is to coach and facilitate student learning and overall comprehension of material, and to measure student learning through both formal and informal forms of assessment, like group projects, student portfolios, and class participation. In the student-centered classroom, teaching and assessment are connected because student learning is continuously measured during teacher instruction.

Learn more about the different teaching styles that use a student-centered approach.



High Tech Approach to Learning

Advancements in technology have propelled the education sector in the last few decades. As the name suggests, the high tech approach to learning utilizes different technology to aid students in their classroom learning. Many educators use computers and tablets in the classroom, and others may use the internet to assign homework. The internet is also beneficial in a classroom setting as it provides unlimited resources. Teachers may also use the internet in order to connect their students with people from around the world.

Below are some tech tools used in classrooms today:

- G Suite External link (Gmail, Docs, Sheets, Classroom, Drive, and Calendar)
- Tablets/laptops
- Education-focused social media platforms (such as schoology External link and seesaw External link)
- Technology accessibility External link for students with disabilities

Teaching and Learning Strategies for Higher Education

The 8-week Teaching and Learning Strategies for Higher Education online short course is delivered by Harvard's Bok Center for Teaching and Learning, in association with HarvardX. Students in this course will engage deeply with the most relevant research on effective teaching methods in the higher education context, while refining their own practices, portfolio, and teaching philosophy.

The University of Dayton School of Education and Health Sciences offers a top-ranked online MSE in

Educational Leadership that prepares students to serve effectively at all levels of leadership from pre-K to grade 12.

Low Tech Approach to Learning

While technology undoubtedly has changed education, many educators opt to use a more traditional, low tech approach to learning. Some learning styles require a physical presence and interaction between the educator and the student. Additionally, some research has shown that low-tech classrooms may boost learning. For example, students who take handwritten notes have better recall than students who take typed notes External link . Another downside of technology in the classroom may be that students exposed to spell check and autocorrect features at an earlier age may be weaker in spelling and writing skills External link . Ultimately, tailoring the learning experience to different types of learners is incredibly important, and sometimes students work better with a low-tech approach.

Here are some examples of low technology usage in different teaching methodologies:

- Kinesthetic learners have a need for movement when learning. Teachers should allow students to move around, speak with hands and gestures.
- Expeditionary learning involves “learning by doing” and participating in a hands-on experience. Students may participate in fieldwork, learning expeditions, projects or case studies to be able to apply knowledge

learned in the classroom to the real world, rather than learning through the virtual world.

- Many types of vocational or practical training cannot be learned virtually, whether it be a laboratory experiment or woodworking.

Through these different approaches to teaching, educators can gain a better understanding of how best to govern their classrooms, implement instruction, and connect with their students. Within each category of teacher and student centeredness and tech usage, there are specific teaching roles or "methods" of instructor behavior that feature their own unique mix of learning and assessment practices. Learn more about each one to find the best fit for your classroom.

Teacher-Centered Methods of Instruction

Direct Instruction (Low Tech)

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As the primary teaching strategy under the teacher-centered approach, direct instruction utilizes passive learning, or the idea that students can learn what they need to through listening and watching very precise instruction. Teachers and professors act as the sole supplier of knowledge, and under the direct instruction model, teachers often utilize systematic, scripted lesson plans. Direct instruction programs include exactly what the teacher should say, and activities that students should complete, for every minute of the lesson.

Because it does not include student preferences or give them opportunities for hands-on or alternative types of learning, direct instruction is extremely teacher-centered. it's also fairly low-tech, often relying on the use of textbooks and workbooks instead of computers and 1:1 devices.

Flipped Classrooms (High Tech)

The idea of the flipped classroom began in 2007 when two teachers began using software that would let them record their live lectures External link. By the next school year, they were implementing pre-recorded lectures and sharing the idea of what became known as the flipped classroom.

Broadly, the flipped classroom label describes the teaching structure that has students watching pre-recorded lessons at home and completing in-class assignments, as opposed to hearing lectures in class and doing homework at home. Teachers who implement the flipped classroom model often film their own instructional videos, but many also use pre-made videos from online sources.

A key benefit of the flipped classroom model is that it allows for students to work at their own pace if that is how the teacher chooses to implement it. In some cases, teachers may assign the same videos to all students, while in others, teachers may choose to allow students to watch new videos as they master topics (taking on a more "differentiated" approach).

But despite this potential for more student-centeredness, flipped classroom models are still mostly based on a teacher's idea of how learning should happen and what information students need, making it chiefly teacher-centered. From a technology perspective, the system hinges on pre-recorded lessons and online activities, meaning both students and teachers need a good internet connection and devices that can access it.

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Sometimes known as tactile learning" or

"hands-on learning", kinesthetic learning is based on the idea of multiple intelligences External link , requiring students to do, make, or create. In a kinesthetic learning environment, students perform physical activities rather than listen to lectures or watch demonstrations. Hands-on experiences, drawing, role-play, building, and the use of drama and sports are all examples of kinesthetic classroom activities.

Though a great way to keep students engaged and, at times, simply awake, very few classrooms employ kinesthetic learning activities exclusively. One reason is that, despite the popularity of learning style theories, there is a lack of research-based evidence that shows that teaching to certain learning styles produces better academic results External link .

One upside is that kinesthetic learning is rarely based on technology, as the method values movement and creativity over technological skills. That means it's cheap and fairly low-barrier to adopt, as well as a welcome break from students' existing screen time. Kinesthetic learning can be more student-centered than teacher-centered when students are given the choice of how to use movement to learn new information or experience new skills, so it's also adaptable to a teacher's particular classroom preferences.

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Teachers can differentiate in a number of ways: how students access content, the types of activities students do to master a concept, what the end product of learning looks like, and how the classroom is set up. Some examples of differentiation include: having students read books at their own reading levels, offering different spelling lists to students, or meeting in small groups to reteach topics.

Though differentiation is focused on individual student needs, it is mostly planned and implemented by the teacher. And technology, though a potential aid, is not a hallmark of the differentiated teaching style, making it a fairly traditional, low-barrier method to adopt.

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In this method of instruction, the teacher might play one or all of the following roles:

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Facilitators place a strong emphasis on the teacher-student relationship. Operating under an open classroom model, there is a de-emphasis on teacher instruction, and both student and educator undergo the learning process together. Student learning loosely guided by the teacher, and is focused on fostering independence, hands-on learning, and exploration	Teachers who operate under the “Personal Model” style are those who lead by example, demonstrating to students how to access and comprehend information. In this teaching model, students learn through observing and copying the teacher’s process.	Teachers act as a “resou students, answering questi reviewing their progress as Teachers play a passive student’s learning; stude active and engaged partici their learning. The main g Delegator is to foster a s autonomy in the learning pr

Teachers encourage students to ask questions and consider what they want to know about the world around them. Students then research their questions, find information and sources that explain key concepts and solve problems they may encounter along the way. Findings might be presented as self-made videos, websites, or formal presentations of research results.

Inquiry-based learning falls under the student-centered approach, in that students play an active and participatory role in their own learning. But teacher facilitation is also extremely key to the process. Usually, during the inquiry cycle, every student is working on a different question or topic. In this environment, teachers ask high-level questions and make research suggestions about the process rather than the content. At the end of the inquiry cycle, students reflect on the experience and what they learned. They also consider how it connects to other topics of interest, as an inquiry on one topic often results in more questions and then an inquiry into new fields External link.

Inquiry-based learning can make great use of technology through online research sites, social media, and the possibility for global connections with people outside of the community. But depending on the subject at hand, it doesn't necessarily require it.

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The learning in this model includes multiple content areas so that students can see how problem-solving can happen in the real world--ideally, their own worlds. A student in a big city, for example, might study statistics about pollution, read information about its effects, and travel to sites in their city that have been impacted by the problem. When they have a good understanding of the circumstances, students and teachers work to find a solution they can actively implement.

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Assessment is also tailored to the individual: schools and classrooms that implement personalized learning use competency-based progression, so that students can move onto the next standards or topics when they've mastered what they're currently working on. That way, students in personalized learning classrooms can progress to work beyond their grade level as they master topics, while students who need additional help have that time built into their daily schedules as well.

There's also room for an emphasis on college and career readiness in personalized learning environments. Students who don't require remediation or extension work can instead work with teachers to nurture social skills and other or 21st-century skills lessons and receive mentoring.

Personalized learning is extremely student centered, but teachers are required to teach lessons, look at frequent assessment data, and meet with students to make any necessary changes to their learning plans. They'll also need to have a certain comfort level with technology: the differentiated and personalized instruction that students receive often come in the form of online lessons and programs, so teachers must be able to navigate virtual platforms with ease.

Read More

- What Does Personalized Learning mean for Educational Design?
- How Technology Changed the Way I Teach My Students

Game-based Learning (High Tech)

Game-based learning comes from the desire to engage students in more active learning in the classroom External link. Because they require students to be problem solvers and use soft skills that they will need as adults, games are a great way to encourage a "mastery" mindset, rather than a focus on grades.

In a game-based learning environment, students work on quests to accomplish a specific goal (learning objective) by choosing actions and experimenting along the way. As students make certain progress or achievements, they can earn badges and experience points, just like they would in their favorite video games.

Game-based learning requires a lot of time and planning on the teachers' part. Fortunately, there is software that makes this process much easier, like 3DGameLab External link and Classcraft External link. Teachers who use this software may be better at differentiating quests for students because of the data the programs provide.

Because teachers play a big role in planning and creating content under this model, game-based learning isn't completely student-centered. But it is still very much focused on the student, who works at their own pace and makes independent choices in a gasified environment.

Read More:

- iPad Education Games
- Teach100 Blog: The Games-Rich Classroom
- Video Games in Learning

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Assessment is also tailored to the individual: schools and classrooms that implement personalized learning use competency-based progression, so that students can move onto the next standards or topics when they’ve mastered what they’re currently working on. That way, students in personalized learning classrooms can progress to work beyond their grade level as they master topics, while students who need additional help have that time built into their daily schedules as well.

There’s also room for an emphasis on college and career readiness in personalized learning environments. Students who don’t require remediation or extension work can instead work with teachers to nurture social skills and other or 21st-century skills lessons and receive mentoring.

Personalized learning is extremely student centered, but teachers are required to teach lessons, look at frequent assessment data, and meet with students to make any necessary changes to their learning plans. They’ll also need to have a certain comfort level with technology: the differentiated and personalized instruction that students receive often come in the form of online lessons and programs, so teachers must be able to navigate virtual platforms with ease.

Read More

- What Does Personalized Learning mean for Educational Design?
- How Technology Changed the Way I Teach My Students

Game-based Learning (High Tech)

Game-based learning comes from the desire to engage students in more active learning in the classroom External link . Because they require students to be problem solvers and use soft skills that they will need as adults, games are a great way to encourage a "mastery" mindset, rather than a focus on grades.

In a game-based learning environment, students work on quests to accomplish a specific goal (learning objective) by choosing actions and experimenting along the way. As students make certain progress or achievements, they can earn badges and experience points, just like they would in their favorite video games.

Game-based learning requires a lot of time and planning on the teachers' part. Fortunately, there is software that makes this process much easier, like 3DGameLab External link and Classcraft External link . Teachers who use this software may be better at differentiating quests for students because of the data the programs provide.

Because teachers play a big role in planning and creating content under this model, game-based learning isn't completely student-centered. But it is still very much focused on the student, who works at their own pace and makes independent choices in a gamified environment.

You're about 30 minutes into your Monday morning energy systems class, and things are not looking good. At least a third of the students are texting or sleeping.

Many of them clearly don't understand much of what you're saying (their midterm exam grades prove it), but they never ask questions. It's been like this since the beginning of the semester and you are getting desperate, so you decide to try something different. You complete your determination of the energy output of a power plant boiler furnace and suddenly say "Suppose they build this exact furnace and the power output is only 380 MW instead of the 550 MW we just calculated. Get into groups of two or three, pick one recorder, and list as many possible reasons as you can think of for the difference, including violations of at least three assumptions in the calculation. I'll give you one minute and then call on a few of you. Go!" The students quickly get into groups—some waking their neighbors in the process—and go to work. You stop them after about a minute, call randomly on several individuals for responses, get more responses from volunteers, and proceed with your lecture. The whole process takes less than three minutes, during which most or all of your students are awake and actively engaged with the course material. When you later ask them to do something similar on a test, surprisingly many of them can do it. That's active learning. [1-5] Most college instructors have heard of it and know that pedagogical experts say they should do it in their classes. If you bring it up with colleagues, though, they will immediately tell you why it's a bad idea (an educational fad, a waste of class time, spoon-feeding, lowering academic standards, a radical conspiracy to destroy the American System of

Higher Education, etc.). In this paper, we offer our definition of active learning; say a few things about how to do it; and try to persuade you that it's none of those evil things listed in the la

(12):Teaching the science of learning

The science of learning has made a considerable contribution to our understanding of effective teaching and learning strategies. However, few instructors outside of the field are privy to this research. In this tutorial review, we focus on six specific cognitive strategies that have received robust support from decades of research: spaced practice, interleaving, retrieval practice, elaboration, concrete examples, and dual coding. We describe the basic research behind each strategy and relevant applied research, present examples of existing and suggested implementation, and make recommendations for further research that would broaden the reach of these strategies.

Significance

Education does not currently adhere to the medical model of evidence-based practice (Roediger, 2013). However, over the past few decades, our field has made significant advances in applying cognitive processes to education. From this work, specific recommendations can be made for students to maximize their learning efficiency (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013;

Roediger, Finn, & Weinstein, 2012). In particular, a review published 10 years ago identified a limited number of study techniques that have received solid evidence from multiple replications testing their effectiveness in and out of the classroom (Pashler et al., 2007). A recent textbook analysis (Pomerance, Greenberg, & Walsh, 2016) took the six key learning strategies from this report by Pashler and colleagues, and found that very few teacher-training textbooks cover any of these six principles – and none cover them all, suggesting that these strategies are not systematically making their way into the classroom. This is the case in spite of multiple recent academic (e.g., Dunlosky et al., 2013) and general audience (e.g., Dunlosky, 2013) publications about these strategies. In this tutorial review, we present the basic science behind each of these six key principles, along with more recent research on their effectiveness in live classrooms, and suggest ideas for pedagogical implementation. The target audience of this review is (a) educators who might be interested in integrating the strategies into their teaching practice, (b) science of learning researchers who are looking for open questions to help determine future research priorities, and (c) researchers in other subfields who are interested in the ways that principles from cognitive psychology have been applied to education.

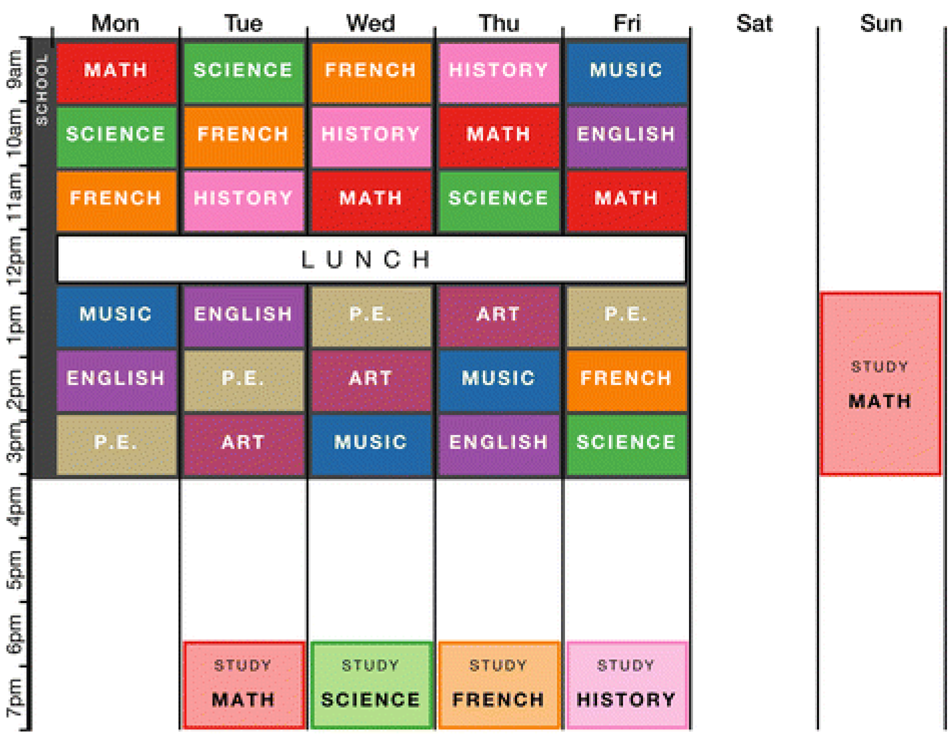
While the typical teacher may not be exposed to this research during teacher training, a small cohort of teachers intensely interested in cognitive psychology has recently emerged. These teachers are mainly based in the UK, and, anecdotally (e.g., Dennis (2016), personal communication), appear to have taken an interest in the science of learning after reading *Make it Stick* (Brown, Roediger, & McDaniel, 2014; see Clark (2016) for an enthusiastic review of this book on a teacher's blog, and "Learning Scientists" (2016c) for a collection). In addition, a grassroots teacher movement has led to the creation of "researchED" – a series of conferences on evidence-based education (researchED, 2013). The teachers who form part of this network frequently discuss cognitive psychology techniques and their applications to education on social media (mainly Twitter; e.g., Fordham, 2016; Penfound, 2016) and on their blogs, such as Evidence Into Practice (https://evidenceintopractice.wordpress.com/), My Learning Journey (http://reflectionsofmyteaching.blogspot.com/), and The Effortful Educator (https://theeffortfuleducator.com/). In general, the teachers who write about these issues pay careful attention to the relevant literature, often citing some of the work described in this review.

These informal writings, while allowing teachers to explore their approach to teaching practice (Luehmann, 2008), give us a unique window into the application of the science of learning to the classroom. By examining these blogs, we can not only observe how basic cognitive research is being applied in the classroom by teachers who are reading it, but also how it is being misapplied, and what questions teachers may be posing that have gone unaddressed in the scientific literature. Throughout this review, we illustrate each strategy with examples of how it can be implemented (see Table 1 and Figs. 1, 2, 3, 4, 5, 6 and 7), as well as with relevant teacher blog posts that reflect on its application, and draw upon this work to pin-point fruitful avenues for further basic and applied research.

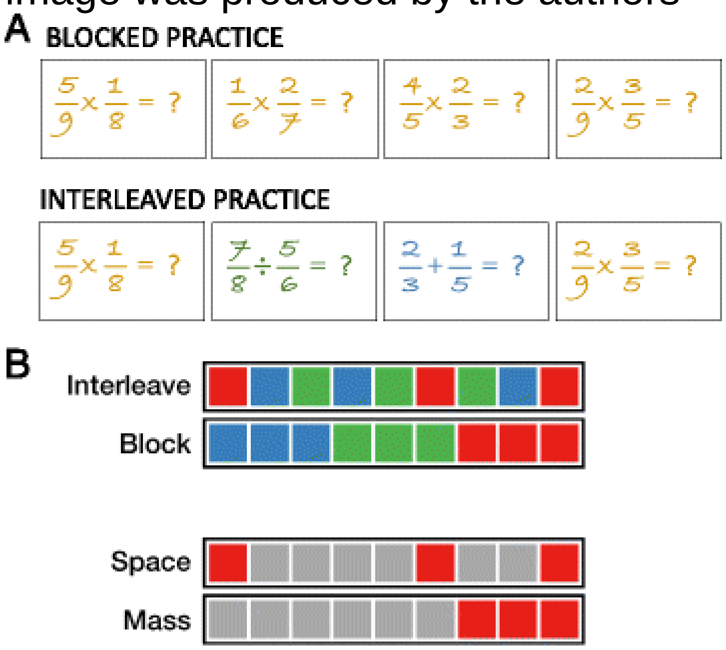
Table 1 Six strategies for effective learning, each illustrated with an implementation example from the biological bases of behavior

Full size table

Fig. 1



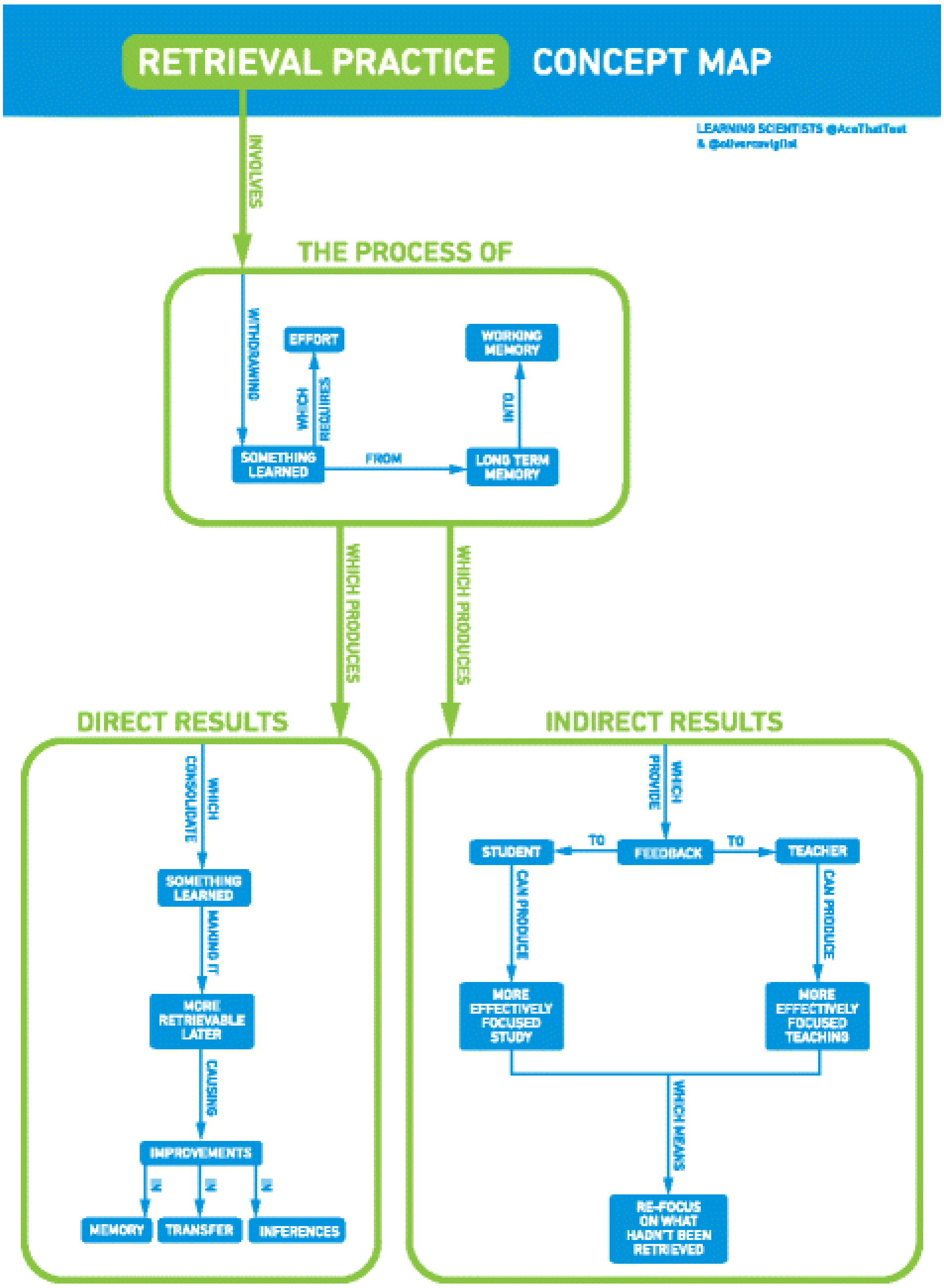
Spaced practice schedule for one week. This schedule is designed to represent a typical timetable of a high-school student. The schedule includes four one-hour study sessions, one longer study session on the weekend, and one rest day. Notice that each subject is studied one day after it is covered in school, to create spacing between classes and study sessions. *Copyright note:* this image was produced by the authors



a Blocked practice and interleaved practice with fraction problems. In the blocked version, students answer four multiplication problems consecutively. In the interleaved version, students answer a multiplication problem followed by a division problem and then an addition problem, before returning to multiplication. For an experiment with a similar setup, see Patel et al. (2016). *Copyright note:* this image was produced by the authors. b Illustration of interleaving and spacing. Each color represents a different homework topic. Interleaving involves alternating between topics, rather than blocking. Spacing involves distributing practice over time, rather than massing. Interleaving inherently involves spacing as other tasks naturally “fill” the spaces between interleaved sessions. *Copyright note:* this image was produced by the authors, adapted from Rohrer (2012)

Full size image

Fig. 3

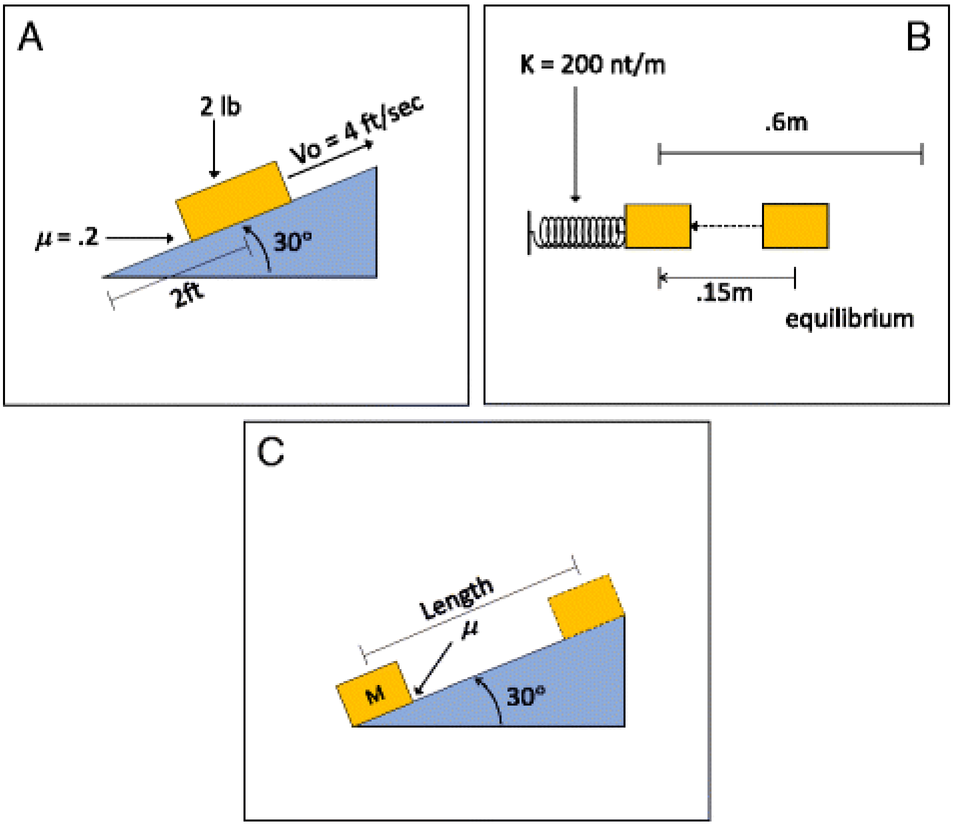


Concept map illustrating the process and resulting benefits of retrieval practice. Retrieval practice involves the process of withdrawing learned information from long-term memory into working memory, which requires effort. This produces direct benefits via the consolidation of learned information, making it easier to remember later and causing improvements in memory, transfer, and inferences. Retrieval practice also produces indirect benefits of feedback to students and teachers, which in turn can lead to more effective study and teaching practices, with a focus on information that was not accurately retrieved. *Copyright note:* this figure originally appeared in a blog post by the first and third authors (http://www.learningscientists.org/blog/2016/4/1-1)

Fig. 4

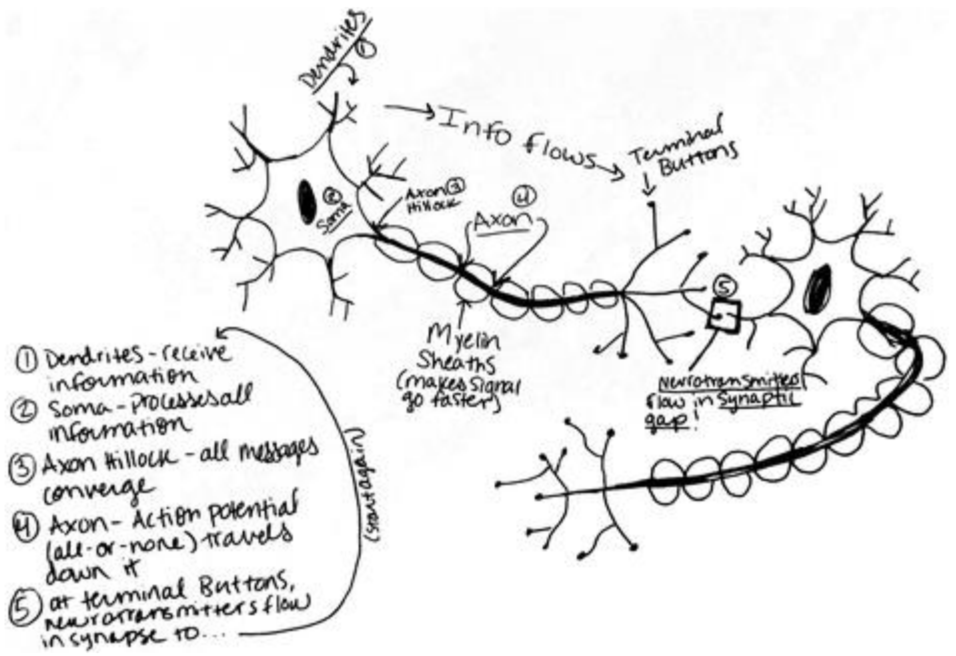
Illustration of “how” and “why” questions (i.e., elaborative interrogation questions) students might ask while studying the physics of flight. To help figure out how physics explains flight, students might ask themselves the following questions: “How does a plane take off?”; “Why does a plane need an engine?”; “How does the upward force (lift) work?”; “Why do the wings have a curved upper surface and a flat lower surface?”; and “Why is there a downwash behind the wings?”. *Copyright note:* the image of the plane was downloaded from Pixabay.com and is free to use, modify, and share

Fig. 5



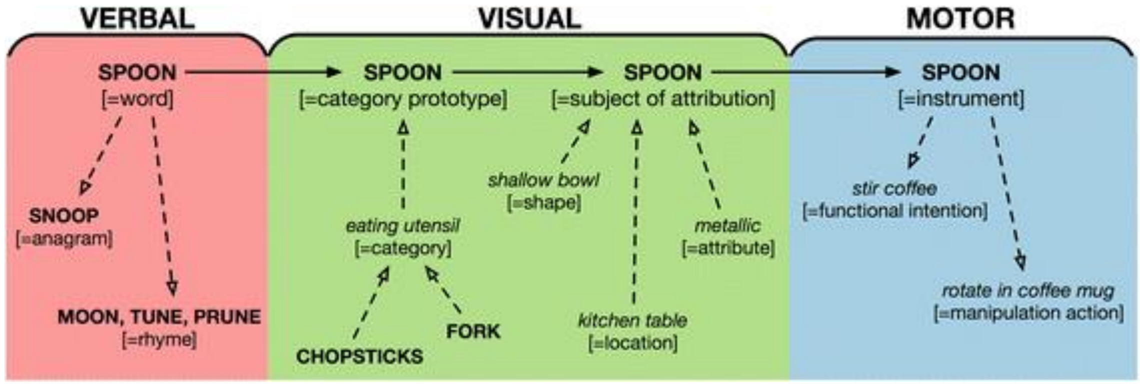
Three examples of physics problems that would be categorized differently by novices and experts. The problems in (a) and (c) look similar on the surface, so novices would group them together into one category. Experts, however, will recognize that the problems in (b) and (c) both relate to the principle of energy conservation, and so will group those two problems into one category instead. *Copyright note:* the figure was produced by the authors, based on figures in Chi et al. (1981)

Fig. 6



Example of how to enhance learning through use of a visual example. Students might view this visual representation of neural communications with the words provided, or they could draw a similar visual representation themselves. *Copyright note:* this figure was produced by the authors

Fig. 7



Example of word properties associated with visual, verbal, and motor coding for the word “SPOON”. A word can evoke multiple types of representation (“codes” in dual coding theory). Viewing a word will automatically evoke verbal representations related to its component letters and phonemes. Words representing objects (i.e., concrete nouns) will also evoke visual representations, including information about similar objects, component parts of the object, and information about where the object is typically found. In some cases, additional codes can also be evoked, such as motor-related properties of the represented object, where contextual information related to the object's functional intention and manipulation action may also be processed automatically when reading the word. *Copyright note:* this figure was produced by the authors and is based on Aylwin (1990; Fig. 2) and Madan and Singhal (2012a, Fig. 3)

Spaced practice

The benefits of spaced (or distributed) practice to learning are arguably one of the strongest contributions that cognitive psychology has made to education (Kang, 2016). The effect is simple: the same amount of repeated studying of the same information spaced out over time will lead to greater retention of that information in the long run, compared with repeated studying of the same information for the same amount of time in one study session. The benefits of distributed practice were first empirically demonstrated in the 19th century. As part of his extensive investigation into his own memory, Ebbinghaus (1885/1913) found that when he spaced out repetitions across 3 days, he could almost halve the number of repetitions necessary to relearn a series of 12 syllables in one day (Chapter 8). He thus concluded that "a suitable distribution of [repetitions] over a space of time is decidedly more advantageous than the massing of them at a single time" (Section 34). For those who want to read more about Ebbinghaus's contribution to memory research, Roediger (1985) provides an excellent summary.

Since then, hundreds of studies have examined spacing effects both in the laboratory and in the classroom (Kang, 2016). Spaced practice appears to be particularly useful at large retention intervals: in the meta-analysis by Cepeda, Pashler, Vul, Wixted, and Rohrer (2006), all studies with a retention interval longer than a month showed a clear benefit of distributed practice. The “new theory of disuse” (Bjork & Bjork, 1992) provides a helpful mechanistic explanation for the benefits of spacing to learning. This theory posits that memories have both retrieval strength and storage strength. Whereas retrieval strength is thought to measure the ease with which a memory can be recalled at a given moment, storage strength (which cannot be measured directly) represents the extent to which a memory is truly embedded in the mind. When studying is taking place, both retrieval strength and storage strength receive a boost. However, the extent to which storage strength is boosted depends upon retrieval strength, and the relationship is negative: the greater the current retrieval strength, the smaller the gains in storage strength. Thus, the information learned through “cramming” will be rapidly forgotten due to high retrieval strength and low storage strength (Bjork & Bjork, 2011), whereas spacing out learning increases storage strength by allowing retrieval strength to wane before restudy.

Teachers can introduce spacing to their students in two broad ways. One involves creating opportunities to revisit information throughout the semester, or even in future semesters. This does involve some up-front planning, and can be difficult to achieve, given time constraints and the need to cover a set curriculum. However, spacing can be achieved with no great costs if teachers set aside a few minutes per class to review information from previous lessons. The second method involves putting the onus to space on the students themselves. Of course, this would work best with older students – high school and above. Because spacing requires advance planning, it is crucial that the teacher helps students plan their studying. For example, teachers could suggest that students schedule study sessions on days that alternate with the days on which a particular class meets (e.g., schedule review sessions for Tuesday and Thursday when the class meets Monday and Wednesday; see Fig. 1 for a more complete weekly spaced practice schedule). It important to note that the spacing effect refers to information that is repeated multiple times, rather than the idea of studying *different* material in one long session versus spaced out in small study sessions over time. However, for teachers and particularly for students planning a study schedule, the subtle difference between the two situations (spacing out restudy opportunities, versus spacing out studying of different information over time) may be lost. Future research should address the effects of spacing out studying of different information over time, whether the same considerations apply in this situation as compared to spacing out restudy opportunities, and how important it is for teachers and students to understand the difference between these two types of spaced practice.

It is important to note that students may feel less confident when they space their learning (Bjork, 1999) than when they cram. This is because spaced learning is harder – but it is this “desirable difficulty” that helps learning in the long term

(Bjork, 1994). Students tend to cram for exams rather than space out their learning. One explanation for this is that cramming does “work”, if the goal is only to pass an exam. In order to change students’ minds about how they schedule their studying, it might be important to emphasize the value of retaining information beyond a final exam in one course.

Ideas for how to apply spaced practice in teaching have appeared in numerous teacher blogs (e.g., Fawcett, 2013; Kraft, 2015; Picciotto, 2009). In England in particular, as of 2013, high-school students need to be able to remember content from up to 3 years back on cumulative exams (General Certificate of Secondary Education (GCSE) and A-level exams; see CIFE, 2012). A-levels in particular determine what subject students study in university and which programs they are accepted into, and thus shape the path of their academic career. A common approach for dealing with these exams has been to include a “revision” (i.e., studying or cramming) period of a few weeks leading up to the high-stakes cumulative exams. Now, teachers who follow cognitive psychology are advocating a shift of priorities to spacing learning over time across the 3 years, rather than teaching a topic once and then intensely reviewing it weeks before the exam (Cox, 2016a; Wood, 2017). For example, some teachers have suggested using homework assignments as an opportunity for spaced practice by giving students homework on previous topics (Rose, 2014). However, questions remain, such as whether spaced practice can ever be effective enough to completely alleviate the need or utility of a cramming period (Cox, 2016b), and how one can possibly figure out the optimal lag for spacing (Benney, 2016; Firth, 2016).

There has been considerable research on the question of optimal lag, and much of it is quite complex; two sessions neither too close together (i.e., cramming) nor too far apart are ideal for retention. In a large-scale study, Cepeda, Vul, Rohrer, Wixted, and Pashler (2008) examined the effects of the gap between study sessions and the interval between study and test across long periods, and found that the optimal gap between study sessions was contingent on the retention interval. Thus, it is not clear how teachers can apply the complex findings on lag to their own classrooms.

A useful avenue of research would be to simplify the research paradigms that are used to study optimal lag, with the goal of creating a flexible, spaced-practice framework that teachers could apply and tailor to their own teaching needs. For example, an Excel macro spreadsheet was recently produced to help teachers plan for lagged lessons (Weinstein-Jones & Weinstein, 2017; see Weinstein & Weinstein-Jones (2017) for a description of the algorithm used in the spreadsheet), and has been used by teachers to plan their lessons (Penfound, 2017). However, one teacher who found this tool helpful also wondered whether the more sophisticated plan was any better than his own method of manually selecting poorly understood material from previous classes for later review (Lovell, 2017). This direction is being actively explored within personalized online learning environments (Kornell & Finn, 2016; Lindsey, Shroyer, Pashler, & Mozer, 2014), but teachers in physical classrooms might need less technologically-driven solutions to teach cohorts of students.

It seems teachers would greatly appreciate a set of guidelines for how to implement spacing in the curriculum in the most effective, but also the most efficient manner. While the cognitive field has made great advances in terms of understanding the mechanisms behind spacing, what teachers need more of are concrete evidence-based tools and guidelines for direct implementation in the classroom. These could include more sophisticated and experimentally tested versions of the software described above (Weinstein-Jones & Weinstein, 2017), or adaptable templates of spaced curricula. Moreover, researchers need to evaluate the effectiveness of these tools in a real classroom environment, over a semester or academic year, in order to give pedagogically relevant evidence-based recommendations to teachers.

Interleaving

Another scheduling technique that has been shown to increase learning is interleaving. Interleaving occurs when different ideas or problem types are tackled in a sequence, as opposed to the more common method of attempting multiple versions of the same problem in a given study session (known as blocking). Interleaving as a principle can be applied in many different ways. One such way involves interleaving different types of problems during learning, which is particularly applicable to subjects such as math and physics (see Fig. 2a for an example with fractions, based on a study by Patel, Liu, & Koedinger, 2016). For example, in a study with college students, Rohrer and Taylor (2007) found that shuffling math problems that involved calculating the volume of different shapes resulted in better test performance 1 week later than when students answered multiple problems about the same type of shape in a row. This pattern of results has also been replicated with younger students, for example 7th grade students learning to solve graph and slope problems (Rohrer, Dedrick, & Stershic, 2015). The proposed explanation for the benefit of interleaving is that switching between different problem types allows students to acquire the ability to choose the right method for solving different types of problems rather than learning only the method itself, and not when to apply it.

Do the benefits of interleaving extend beyond problem solving? The answer appears to be yes. Interleaving can be helpful in other situations that require discrimination, such as inductive learning. Kornell and Bjork (2008) examined the effects of interleaving in a task that might be pertinent to a student of the history of art: the ability to match paintings to their respective painters. Students who studied different painters' paintings interleaved at study were more successful on a later identification test than were participants who studied the paintings blocked by painter. Birnbaum, Kornell, Bjork, and Bjork (2013) proposed the discriminative-contrast hypothesis to explain that interleaving enhances learning by allowing the comparison between exemplars of different categories. They found support for this hypothesis in a set of experiments with bird categorization: participants benefited from interleaving and also from spacing, but not when the spacing interrupted side-by-side comparisons of birds from different categories.

Another type of interleaving involves the interleaving of study and test opportunities. This type of interleaving has been applied, once again, to problem solving, whereby students alternate between attempting a problem and viewing a worked example (Trafton & Reiser, 1993); this pattern appears to be superior to answering a string of problems in a row, at least with respect to the amount of time it takes to achieve mastery of a procedure (Corbett, Reed, Hoffmann, MacLaren, & Wagner, 2010). The benefits of interleaving study and test opportunities – rather than blocking study followed by attempting to answer problems or questions – might arise due to a process known as "test-potentiated learning". That is, a study opportunity that immediately follows a retrieval attempt may be more fruitful than when that same studying was not preceded by retrieval (Arnold & McDermott, 2013).

For problem-based subjects, the interleaving technique is straightforward: simply mix questions on homework and quizzes with previous materials (which takes care of spacing as well); for languages, mix vocabulary themes rather than blocking by theme (Thomson & Mehring, 2016). But interleaving as an educational strategy ought to be presented to teachers with some caveats. Research has focused on interleaving material that is somewhat related (e.g., solving different mathematical equations, Rohrer et al., 2015), whereas students sometimes ask whether they should interleave material from different subjects – a practice that has not received empirical support (Hausman & Kornell, 2014). When advising students how to study independently, teachers should thus proceed with caution. Since it is easy for younger students to confuse this type of unhelpful interleaving with the more helpful interleaving of related information, it may be best for teachers of younger grades to create opportunities for interleaving in homework and quiz assignments rather than putting the onus on the students themselves to make use of the technique. Technology can be very helpful here, with apps such as Quizlet, Memrise, Anki, Synap, Quiz Champ, and many others (see also “Learning Scientists”, 2017) that not only allow instructor-created quizzes to be taken by students, but also provide built-in interleaving algorithms so that the burden does not fall on the teacher or the student to carefully plan which items are interleaved when.

An important point to consider is that in educational practice, the distinction between spacing and interleaving can be difficult to delineate. The gap between the scientific and classroom definitions of interleaving is demonstrated by teachers’ own writings about this technique. When they write about interleaving, teachers often extend the term to connote a curriculum that involves returning to topics multiple times throughout the year (e.g., Kirby, 2014; see “Learning Scientists” (2016a) for a collection of similar blog posts by several other teachers). The “interleaving” of topics throughout the curriculum produces an effect that is more akin to what cognitive psychologists call “spacing” (see Fig. 2b for a visual representation of the difference between interleaving and spacing). However, cognitive psychologists have not examined the effects of structuring the curriculum in this way, and open questions remain: does repeatedly circling back to previous topics throughout the semester interrupt the learning of new information? What are some effective techniques for interleaving old and new information within one class? And how does one determine the balance between old and new information?

Retrieval practice

While tests are most often used in educational settings for assessment, a lesser-known benefit of tests is that they actually improve memory of the tested information. If we think of our memories as libraries of information, then it may seem surprising that retrieval (which happens when we take a test) improves memory; however, we know from a century of research that retrieving knowledge actually strengthens it (see Karpicke, Lehman, & Aue, 2014). Testing was shown to strengthen memory as early as 100 years ago (Gates, 1917), and there has been a surge of research in the last decade on the mnemonic benefits of testing, or *retrieval practice*. Most of the research on the effectiveness of retrieval practice has been done with college students (see Roediger & Karpicke, 2006; Roediger, Putnam, & Smith, 2011), but retrieval-based learning has been shown to be effective at producing learning for a wide range of ages, including preschoolers (Fritz, Morris, Nolan, & Singleton, 2007), elementary-aged children (e.g., Karpicke, Blunt, & Smith, 2016; Karpicke, Blunt, Smith, & Karpicke, 2014; Lipko-Speed, Dunlosky, & Rawson, 2014; Marsh, Fazio, & Goswick, 2012; Ritchie, Della Sala, & McIntosh, 2013), middle-school students (e.g., McDaniel, Thomas, Agarwal, McDermott, & Roediger, 2013; McDermott, Agarwal, D'Antonio, Roediger, & McDaniel, 2014), and high-school students (e.g., McDermott et al., 2014). In addition, the effectiveness of retrieval-based learning has been extended beyond simple testing to other activities in which retrieval practice can be integrated, such as concept mapping (Blunt & Karpicke, 2014; Karpicke, Blunt, et al., 2014; Ritchie et al., 2013).

A debate is currently ongoing as to the effectiveness of retrieval practice for more complex materials (Karpicke & Aue, 2015; Roelle & Berthold, 2017; Van Gog & Sweller, 2015). Practicing retrieval has been shown to improve the application of knowledge to new situations (e.g., Butler, 2010; Dirkx, Kester, & Kirschner, 2014); McDaniel et al., 2013; Smith, Blunt, Whiffen, & Karpicke, 2016); but see Tran, Rohrer, and Pashler (2015) and Wooldridge, Bugg, McDaniel, and Liu (2014), for retrieval practice studies that showed limited or no increased transfer compared to restudy. Retrieval practice effects on higher-order learning may be more sensitive than fact learning to encoding factors, such as the way material is presented during study (Eglington & Kang, 2016). In addition, retrieval practice may be more beneficial for higher-order learning if it includes more scaffolding (Fiechter & Benjamin, 2017; but see Smith, Blunt, et al., 2016) and targeted practice with application questions (Son & Rivas, 2016).

How does retrieval practice help memory? Figure 3 illustrates both the direct and indirect benefits of retrieval practice identified by the literature. The act of retrieval itself is thought to strengthen memory (Karpicke, Blunt, et al., 2014; Roediger & Karpicke, 2006; Smith, Roediger, & Karpicke, 2013). For example, Smith et al. (2013) showed that if students brought information to mind without actually producing it (covert retrieval), they remembered the information just as well as if they overtly produced the retrieved information (overt retrieval). Importantly, both overt and covert retrieval practice improved memory over control groups without retrieval practice, even when feedback was not provided. The fact that bringing information to mind in the absence of feedback or restudy opportunities improves memory leads researchers to conclude that it is the act of retrieval – thinking back to bring information to mind – that improves memory of that information.

The benefit of retrieval practice depends to a certain extent on successful retrieval (see Karpicke, Lehman, et al., 2014). For example, in Experiment 4 of Smith et al. (2013), students successfully retrieved 72% of the information during retrieval practice. Of course, retrieving 72% of the information was compared to a restudy control group, during which students were re-exposed to 100% of the information, creating a bias in favor of the restudy condition. Yet retrieval led to superior memory later compared to the restudy control. However, if retrieval success is extremely low, then it is unlikely to improve memory (e.g., Karpicke, Blunt, et al., 2014), particularly in the absence of feedback. On the other hand, if retrieval-based learning situations are constructed in such a way that ensures high levels of success, the act of bringing the information to mind may be undermined, thus making it less beneficial. For example, if a student reads a sentence and then immediately covers the sentence and recites it out loud, they are likely not retrieving the information but rather just keeping the information in their working memory long enough to recite it again (see Smith, Blunt, et al., 2016 for a discussion of this point). Thus, it is important to balance success of retrieval with overall difficulty in retrieving the information (Smith & Karpicke, 2014; Weinstein, Nunes, & Karpicke, 2016). If initial retrieval success is low, then feedback can help improve the overall benefit of practicing retrieval (Kang, McDermott, & Roediger, 2007; Smith & Karpicke, 2014). Kornell, Klein, and Rawson (2015), however, found that it was the retrieval attempt and not the correct production of information that produced the retrieval practice benefit – as long as the correct answer was provided after an unsuccessful attempt, the benefit was the same as for a successful retrieval attempt in this set of studies. From a practical perspective, it would be helpful for teachers to know when retrieval attempts in the absence of success are helpful, and when they are not. There may also be additional reasons beyond retrieval benefits that would push teachers towards retrieval practice activities that produce some success amongst students; for example, teachers may hesitate to give students retrieval practice exercises that are too difficult, as this may negatively affect self-efficacy and confidence.

In addition to the fact that bringing information to mind directly improves memory for that information, engaging in retrieval practice can produce indirect benefits as well (see Roediger et al., 2011). For example, research by Weinstein, Gilmore, Szpunar, and McDermott (2014) demonstrated that when students expected to be tested, the increased test expectancy led to better-quality encoding of new information. Frequent testing can also serve to decrease mind-wandering – that is, thoughts that are unrelated to the material that students are supposed to be studying (Szpunar, Khan, & Schacter, 2013).

Practicing retrieval is a powerful way to improve meaningful learning of information, and it is relatively easy to implement in the classroom. For example, requiring students to practice retrieval can be as simple as asking students to put their class materials away and try to write out everything they know about a topic. Retrieval-based learning strategies are also flexible. Instructors can give students practice tests (e.g., short-answer or multiple-choice, see Smith & Karpicke, 2014), provide open-ended prompts for the students to recall information (e.g., Smith, Blunt, et al., 2016) or ask their students to create concept maps from memory (e.g., Blunt & Karpicke, 2014). In one study, Weinstein et al. (2016) looked at the effectiveness of inserting simple short-answer questions into online learning modules to see whether they improved student performance. Weinstein and colleagues also manipulated the placement of the questions. For some students, the questions were interspersed throughout the module, and for other students the questions were all presented at the end of the module. Initial success on the short-answer questions was higher when the questions were interspersed throughout the module. However, on a later test of learning from that module, the original placement of the questions in the module did not matter for performance. As with spaced practice, where the optimal gap between study sessions is contingent on the retention interval, the optimum difficulty and level of success during retrieval practice may also depend on the retention interval. Both groups of students who answered questions performed better on the delayed test compared to a control group without question opportunities during the module. Thus, the important thing is for instructors to provide opportunities for retrieval practice during learning. Based on previous research, any activity that promotes the successful retrieval of information should improve learning.

Retrieval practice has received a lot of attention in teacher blogs (see “Learning Scientists” (2016b) for a collection). A common theme seems to be an emphasis on low-stakes (Young, 2016) and even no-stakes (Cox, 2015) testing, the goal of which is to increase learning rather than assess performance. In fact, one well-known charter school in the UK has an official homework policy grounded in retrieval practice: students are to test themselves on subject knowledge for 30 minutes every day in lieu of standard homework (Michaela Community School, 2014). The utility of homework, particularly for younger children, is often a hotly debated topic outside of academia (e.g., Shumaker, 2016; but see Jones (2016) for an opposing viewpoint and Cooper (1989) for the original research the blog posts were based on). Whereas some research shows clear links between homework and academic achievement (Valle et al., 2016), other researchers have questioned the effectiveness of homework (Dettmers, Trautwein, & Lüdtke, 2009). Perhaps amending homework to involve retrieval practice might make it more effective; this remains an open empirical question.

One final consideration is that of test anxiety. While retrieval practice can be very powerful at improving memory, some research shows that pressure during retrieval can undermine some of the learning benefit. For example, Hinze and Rapp (2014) manipulated pressure during quizzing to create high-pressure and low-pressure conditions. On the quizzes themselves, students performed equally well. However, those in the high-pressure condition did not perform as well on a criterion test later compared to the low-pressure group. Thus, test anxiety may reduce the learning benefit of retrieval practice. Eliminating all high-pressure tests is probably not possible, but instructors can provide a number of low-stakes retrieval opportunities for students to help increase learning. The use of low-stakes testing can serve to decrease test anxiety (Khanna, 2015), and has recently been shown to negate the detrimental impact of stress on learning (Smith, Floerke, & Thomas, 2016). This is a particularly important line of inquiry to pursue for future research, because many teachers who are not familiar with the effectiveness of retrieval practice may be put off by the implied pressure of “testing”, which evokes the much maligned high-stakes standardized tests (e.g., McHugh, 2013).

Elaboration

Elaboration involves connecting new information to pre-existing knowledge. Anderson (1983, p.285) made the following claim about elaboration: “One of the most potent manipulations that can be performed in terms of increasing a subject’s memory for material is to have the subject elaborate on the to-be-remembered material.” Postman (1976, p. 28) defined elaboration most parsimoniously as “additions to nominal input”, and Hirshman (2001, p. 4369) provided an elaboration on this definition (pun intended!), defining elaboration as “A conscious, intentional process that associates to-be-remembered information with other information in memory.” However, in practice, elaboration could mean many different things. The common thread in all the definitions is that elaboration involves adding features to an existing memory.

One possible instantiation of elaboration is thinking about information on a deeper level. The levels (or “depth”) of processing framework, proposed by Craik and Lockhart (1972), predicts that information will be remembered better if it is processed more deeply in terms of meaning, rather than shallowly in terms of form. The leves of processing framework has, however, received a number of criticisms (Craik, 2002). One major problem with this framework is that it is difficult to measure “depth”. And if we are not able to actually measure depth, then the argument can become circular: is it that something was remembered better because it was studied more deeply, or do we conclude that it must have been studied more deeply because it is remembered better? (See Lockhart & Craik, 1990, for further discussion of this issue).

Another mechanism by which elaboration can confer a benefit to learning is via improvement in organization (Bellezza, Cheesman, & Reddy, 1977; Mandler, 1979). By this view, elaboration involves making information more integrated and organized with existing knowledge structures. By connecting and integrating the to-be-learned information with other concepts in memory, students can increase the extent to which the ideas are organized in their minds, and this increased organization presumably facilitates the reconstruction of the past at the time of retrieval.

Elaboration is such a broad term and can include so many different techniques that it is hard to claim that elaboration will always help learning. There is, however, a specific technique under the umbrella of elaboration for which there is relatively strong evidence in terms of effectiveness (Dunlosky et al., 2013; Pashler et al., 2007). This technique is called elaborative interrogation, and involves students questioning the materials that they are studying (Pressley, McDaniel, Turnure, Wood, & Ahmad, 1987). More specifically, students using this technique would ask "how" and "why" questions about the concepts they are studying (see Fig. 4 for an example on the physics of flight). Then, crucially, students would try to answer these questions – either from their materials or, eventually, from memory (McDaniel & Donnelly, 1996). The process of figuring out the answer to the questions – with some amount of uncertainty (Overoye & Storm, 2015) – can help learning. When using this technique, however, it is important that students check their answers with their materials or with the teacher; when the content generated through elaborative interrogation is poor, it can actually hurt learning (Clinton, Alibali, & Nathan, 2016).

Students can also be encouraged to self-explain concepts to themselves while learning (Chi, De Leeuw, Chiu, & LaVancher, 1994). This might involve students simply saying out loud what steps they need to perform to solve an equation. Aleven and Koedinger (2002) conducted two classroom studies in which students were either prompted by a "cognitive tutor" to provide self-explanations during a problem-solving task or not, and found that the self-explanations led to improved performance. According to the authors, this approach could scale well to real classrooms. If possible and relevant, students could even perform actions alongside their self-explanations (Cohen, 1981; see also the enactment effect, Hainselin, Picard, Manolli, Vankerkore-Candas, & Bourdin, 2017). Instructors can scaffold students in these types of activities by providing self-explanation prompts throughout to-be-learned material (O'Neil et al., 2014). Ultimately, the greatest potential benefit of accurate self-explanation or elaboration is that the student will be able to transfer their knowledge to a new situation (Rittle-Johnson, 2006).

The technical term "elaborative interrogation" has not made it into the vernacular of educational bloggers (a search on https://educationechochamberuncut.wordpress.com, which consolidates over 3,000 UK-based teacher blogs, yielded zero results for that term). However, a few teachers have blogged about elaboration more generally (e.g., Hobbiss, 2016) and deep questioning specifically (e.g., Class Teaching, 2013), just without using the specific terminology. This strategy in particular may benefit from a more open dialog between researchers and teachers to facilitate the use of elaborative interrogation in the classroom and to address possible barriers to implementation. In terms of advancing the scientific understanding of elaborative interrogation in a classroom setting, it would be informative to conduct a larger-scale intervention to see whether having students elaborate during reading actually helps their understanding. It would also be useful to know whether the students really need to generate their own elaborative interrogation ("how" and "why") questions, versus answering questions provided by others. How long should students persist to find the answers? When is the right time to have students engage in this task, given the levels of expertise required to do it well (Clinton et al., 2016)? Without knowing the answers to these questions, it may be too early for us to instruct teachers to use this technique in their classes. Finally, elaborative interrogation takes a long time. Is this time efficiently spent? Or, would it be better to have the students try to answer a few questions, pool their information as a class, and then move to practicing retrieval of the information?

Concrete examples

Providing supporting information can improve the learning of key ideas and concepts. Specifically, using concrete examples to supplement content that is more conceptual in nature can make the ideas easier to understand and remember. Concrete examples can provide several advantages to the learning process: (a) they can concisely convey information, (b) they can provide students with more concrete information that is easier to remember, and (c) they can take advantage of the superior memorability of pictures relative to words (see “Dual Coding”).

Words that are more concrete are both recognized and recalled better than abstract words (Gorman, 1961; e.g., “button” and “bound,” respectively). Furthermore, it has been demonstrated that information that is more concrete and imageable enhances the learning of associations, even with abstract content (Caplan & Madan, 2016; Madan, Glaholt, & Caplan, 2010; Paivio, 1971). Following from this, providing concrete examples during instruction should improve retention of related abstract concepts, rather than the concrete examples alone being remembered better. Concrete examples can be useful both during instruction and during practice problems. Having students actively explain how two examples are similar and encouraging them to extract the underlying structure on their own can also help with transfer. In a laboratory study, Berry (1983) demonstrated that students performed well when given concrete practice problems, regardless of the use of verbalization (akin to elaborative interrogation), but that verbalization helped students transfer understanding from concrete to abstract problems. One particularly important area of future research is determining how students can best make the link between concrete examples and abstract ideas.

Since abstract concepts are harder to grasp than concrete information (Paivio, Walsh, & Bons, 1994), it follows that teachers ought to illustrate abstract ideas with concrete examples. However, care must be taken when selecting the examples. LeFevre and Dixon (1986) provided students with both concrete examples and abstract instructions and found that when these were inconsistent, students followed the concrete examples rather than the abstract instructions, potentially constraining the application of the abstract concept being taught. Lew, Fukawa-Connelly, Mejí-Ramos, and Weber (2016) used an interview approach to examine why students may have difficulty understanding a lecture. Responses indicated that some issues were related to understanding the overarching topic rather than the component parts, and to the use of informal colloquialisms that did not clearly follow from the material being taught. Both of these issues could have potentially been addressed through the inclusion of a greater number of relevant concrete examples.

One concern with using concrete examples is that students might only remember the examples – especially if they are particularly memorable, such as fun or gimmicky examples – and will not be able to transfer their understanding from one example to another, or more broadly to the abstract concept. However, there does not seem to be any evidence that fun relevant examples actually hurt learning by harming memory for important information. Instead, fun examples and jokes tend to be more memorable, but this boost in memory for the joke does not seem to come at a cost to memory for the underlying concept (Baldassari & Kelley, 2012). However, two important caveats need to be highlighted. First, to the extent that the more memorable content is not relevant to the concepts of interest, learning of the target information can be compromised (Harp & Mayer, 1998). Thus, care must be taken to ensure that all examples and gimmicks are, in fact, related to the core concepts that the students need to acquire, and do not contain irrelevant perceptual features (Kaminski & Sloutsky, 2013).

The second issue is that novices often notice and remember the surface details of an example rather than the underlying structure. Experts, on the other hand, can extract the underlying structure from examples that have divergent surface features (Chi, Feltovich, & Glaser, 1981; see Fig. 5 for an example from physics). Gick and Holyoak (1983) tried to get students to apply a rule from one problem to another problem that appeared different on the surface, but was structurally similar. They found that providing multiple examples helped with this transfer process compared to only using one example – especially when the examples provided had different surface details. More work is also needed to determine how many examples are sufficient for generalization to occur (and this, of course, will vary with contextual factors and individual differences). Further research on the continuum between concrete/specific examples and more abstract concepts would also be informative. That is, if an example is not concrete enough, it may be too difficult to understand. On the other hand, if the example is too concrete, that could be detrimental to generalization to the more abstract concept (although a diverse set of very concrete examples may be able to help with this). In fact, in a controversial article, Kaminski, Sloutsky, and Heckler (2008) claimed that abstract examples were more effective than concrete examples. Later rebuttals of this paper contested whether the abstract versus concrete distinction was clearly defined in the original study (see Reed, 2008, for a collection of letters on the subject). This ideal point along the concrete-abstract continuum might also interact with development.

Finding teacher blog posts on concrete examples proved to be more difficult than for the other strategies in this review. One optimistic possibility is that teachers frequently use concrete examples in their teaching, and thus do not think of this as a specific contribution from cognitive psychology; the one blog post we were able to find that discussed concrete examples suggests that this might be the case (Boulton, 2016). The idea of "linking abstract concepts with concrete examples" is also covered in 25% of teacher-training textbooks used in the US, according to the report by Pomerance et al. (2016); this is the second most frequently covered of the six strategies, after "posing probing questions" (i.e., elaborative interrogation). A useful direction for future research would be to establish how teachers are using concrete examples in their practice, and whether we can make any suggestions for improvement based on research into the science of learning. For example, if two examples are better than one (Bauernschmidt, 2017), are additional examples also needed, or are there diminishing returns from providing more examples? And, how can teachers best ensure that concrete examples are consistent with prior knowledge (Reed, 2008)?

Dual coding

Both the memory literature and folk psychology support the notion of visual examples being beneficial—the adage of "a picture is worth a thousand words" (traced back to an advertising slogan from the 1920s; Meider, 1990). Indeed, it is well-understood that more information can be conveyed through a simple illustration than through several paragraphs of text (e.g., Barker & Manji, 1989; Mayer & Gallini, 1990). Illustrations can be particularly helpful when the described concept involves several parts or steps and is intended for individuals with low prior knowledge (Eitel & Scheiter, 2015; Mayer & Gallini, 1990). Figure 6 provides a concrete example of this, illustrating how information can flow through neurons and synapses.

In addition to being able to convey information more succinctly, pictures are also more memorable than words (Paivio & Csapo, 1969, 1973). In the memory literature, this is referred to as the *picture superiority effect*, and dual coding theory was developed in part to explain this effect. Dual coding follows from the notion of text being accompanied by complementary visual information to enhance learning. Paivio (1971, 1986) proposed dual coding theory as a mechanistic account for the integration of multiple information “codes” to process information. In this theory, a code corresponds to a modal or otherwise distinct representation of a concept—e.g., “mental images for ‘book’ have visual, tactual, and other perceptual qualities similar to those evoked by the referent objects on which the images are based” (Clark & Paivio, 1991, p. 152). Aylwin (1990) provides a clear example of how the word “dog” can evoke verbal, visual, and enactive representations (see Fig. 7 for a similar example for the word “SPOON”, based on Aylwin, 1990 (Fig. 2) and Madan & Singhal, 2012a (Fig. 3)). Codes can also correspond to emotional properties (Clark & Paivio, 1991; Paivio, 2013). Clark and Paivio (1991) provide a thorough review of dual coding theory and its relation to education, while Paivio (2007) provides a comprehensive treatise on dual coding theory. Broadly, dual coding theory suggests that providing multiple representations of the same information enhances learning and memory, and that information that more readily evokes additional representations (through automatic imagery processes) receives a similar benefit.

Paivio and Csapo (1973) suggest that verbal and imaginal codes have independent and additive effects on memory recall. Using visuals to improve learning and memory has been particularly applied to vocabulary learning (Danan, 1992; Sadoski, 2005), but has also shown success in other domains such as in health care (Hartland, Biddle, & Fallacaro, 2008). To take advantage of dual coding, verbal information should be accompanied by a visual representation when possible. However, while the studies discussed all indicate that the use of multiple representations of information is favorable, it is important to acknowledge that each representation also increases cognitive load and can lead to over-saturation (Mayer & Moreno, 2003).

Given that pictures are generally remembered better than words, it is important to ensure that the pictures students are provided with are helpful and relevant to the content they are expected to learn. McNeill, Uttal, Jarvin, and Sternberg (2009) found that providing visual examples decreased conceptual errors. However, McNeill et al. also found that when students were given visually rich examples, they performed more poorly than students who were not given any visual example, suggesting that the visual details can at times become a distraction and hinder performance. Thus, it is important to consider that images used in teaching are clear and not ambiguous in their meaning (Schwartz, 2007).

Further broadening the scope of dual coding theory, Engelkamp and Zimmer (1984) suggest that motor movements, such as "turning the handle," can provide an additional motor code that can improve memory, linking studies of motor actions (enactment) with dual coding theory (Clark & Paivio, 1991; Engelkamp & Cohen, 1991; Madan & Singhal, 2012c). Indeed, enactment effects appear to primarily occur during learning, rather than during retrieval (Peterson & Mulligan, 2010). Along similar lines, Wammes, Meade, and Fernandes (2016) demonstrated that generating drawings can provide memory benefits beyond what could otherwise be explained by visual imagery, picture superiority, and other memory enhancing effects. Providing convergent evidence, even when overt motor actions are not critical in themselves, words representing functional objects have been shown to enhance later memory (Madan & Singhal, 2012b; Montefinese, Ambrosini, Fairfield, & Mammarella, 2013). This indicates that motoric processes can improve memory similarly to visual imagery, similar to memory differences for concrete vs. abstract words. Further research suggests that automatic motor simulation for functional objects is likely responsible for this memory benefit (Madan, Chen, & Singhal, 2016).

When teachers combine visuals and words in their educational practice, however, they may not always be taking advantage of dual coding – at least, not in the optimal manner. For example, a recent discussion on Twitter centered around one teacher's decision to have 7th Grade students replace certain words in their science laboratory report with a picture of that word (e.g., the instructions read "using a syringe …" and a picture of a syringe replaced the word; Turner, 2016a). Other teachers argued that this was not dual coding (Beaven, 2016; Williams, 2016), because there were no longer two different representations of the information. The first teacher maintained that dual coding was preserved, because this laboratory report with pictures was to be used alongside the original, fully verbal report (Turner, 2016b). This particular implementation – having students replace individual words with pictures – has not been examined in the cognitive literature, presumably because no benefit would be expected. In any case, we need to be clearer about implementations for dual coding, and more research is needed to clarify how teachers can make use of the benefits conferred by multiple representations and picture superiority.

Critically, dual coding theory is distinct from the notion of “learning styles,” which describe the idea that individuals benefit from instruction that matches their modality preference. While this idea is pervasive and individuals often subjectively feel that they have a preference, evidence indicates that the learning styles theory is not supported by empirical findings (e.g., Kavale, Hirshoren, & Forness, 1998; Pashler, McDaniel, Rohrer, & Bjork, 2008; Rohrer & Pashler, 2012). That is, there is no evidence that instructing students in their preferred learning style leads to an overall improvement in learning (the “meshing” hypothesis). Moreover, learning styles have come to be described as a myth or urban legend within psychology (Coffield, Moseley, Hall, & Ecclestone, 2004; Hattie & Yates, 2014; Kirschner & van Merriënboer, 2013; Kirschner, 2017); skepticism about learning styles is a common stance amongst evidence-informed teachers (e.g., Saunders, 2016). Providing evidence against the notion of learning styles, Kraemer, Rosenberg, and Thompson-Schill (2009) found that individuals who scored as “verbalizers” and “visualizers” did not perform any better on experimental trials matching their preference. Instead, it has recently been shown that learning through one’s preferred learning style is associated with elevated subjective judgements of learning, but not objective performance (Knoll, Otani, Skeel, & Van Horn, 2017). In contrast to learning styles, dual coding is based on providing additional, complementary forms of information to enhance learning, rather than tailoring instruction to individuals' preferences.

Conclusion

Genuine educational environments present many opportunities for combining the strategies outlined above. Spacing can be particularly potent for learning if it is combined with retrieval practice. The additive benefits of retrieval practice and spacing can be gained by engaging in retrieval practice multiple times (also known as distributed practice; see Cepeda et al., 2006). Interleaving naturally entails spacing if students interleave old and new material. Concrete examples can be both verbal and visual, making use of dual coding. In addition, the strategies of elaboration, concrete examples, and dual coding all work best when used as part of retrieval practice. For example, in the concept-mapping studies mentioned above (Blunt & Karpicke, 2014; Karpicke, Blunt, et al., 2014), creating concept maps while looking at course materials (e.g., a textbook) was not as effective for later memory as creating concept maps from memory. When practicing elaborative interrogation, students can start off answering the "how" and "why" questions they pose for themselves using class materials, and work their way up to answering them from memory. And when interleaving different problem types, students should be practicing answering them rather than just looking over worked examples.

But while these ideas for strategy combinations have empirical bases, it has not yet been established whether the benefits of the strategies to learning are additive, super-additive, or, in some cases, incompatible. Thus, future research needs to (a) better formalize the definition of each strategy (particularly critical for elaboration and dual coding), (b) identify best practices for implementation in the classroom, (c) delineate the boundary conditions of each strategy, and (d) strategically investigate interactions between the six strategies we outlined in this manuscript.

References

1. Aleven, V. A., & Koedinger, K. R. (2002). An effective metacognitive strategy: learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science, 26*, 147–179.

   Article Google Scholar

2. Anderson, J. R. (1983). A spreading activation theory of memory. *Journal of Verbal Learning and Verbal Behavior, 22*, 261–295.

   Article Google Scholar

3. Arnold, K. M., & McDermott, K. B. (2013). Test-potentiated learning: distinguishing

between direct and indirect effects of tests. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*, 940–945.

PubMed Google Scholar

4. Aylwin, S. (1990). Imagery and affect: big questions, little answers. In P. J. Thompson, D. E. Marks, & J. T. E. Richardson (Eds.), *Imagery: Current developments*. New York: International Library of Psychology.

Google Scholar

5. Baldassari, M. J., & Kelley, M. (2012). Make'em laugh? The mnemonic effect of humor in a speech. *Psi Chi Journal of Psychological Research, 17*, 2–9.

Article Google Scholar

6. Barker, P. G., & Manji, K. A. (1989). Pictorial dialogue methods. *International Journal of Man-Machine Studies, 31*, 323–347.

Article Google Scholar

7. Bauernschmidt, A. (2017). GUEST POST: two examples are better than one. [Blog post]. *The Learning Scientists Blog*. Retrieved from http://www.learningscientists.org/blog/2017/5/30-1. Accessed 25 Dec 2017.
8. Beaven, T. (2016). @doctorwhy @FurtherEdagogy @doc_kristy Right, I thought the whole point of dual coding was to use TWO codes: pics + words of the SAME info? [Tweet]. Retrieved

from https://twitter.com/TitaBeaven/status/807504041341308929. Accessed 25 Dec 2017.

9. Bellezza, F. S., Cheesman, F. L., & Reddy, B. G. (1977). Organization and semantic elaboration in free recall. *Journal of Experimental Psychology: Human Learning and Memory, 3*, 539–550.

Google Scholar

10. Benney, D. (2016). (Trying to apply) spacing in a content heavy subject [Blog post]. Retrieved from https://mrbenney.wordpress.com/2016/10/16/trying-to-apply-spacing-in-science/. Accessed 25 Dec 2017.

11. Berry, D. C. (1983). Metacognitive experience and transfer of logical reasoning. *Quarterly Journal of Experimental Psychology, 35A*, 39–49.

Article Google Scholar

12. Birnbaum, M. S., Kornell, N., Bjork, E. L., & Bjork, R. A. (2013). Why interleaving enhances inductive learning: the roles of discrimination and retrieval. *Memory & Cognition, 41*, 392–402.

Article Google Scholar

13. Bjork, R. A. (1999). Assessing our own competence: heuristics and illusions. In D. Gopher & A. Koriat (Eds.), *Attention and peformance XVII. Cognitive regulation of performance: Interaction of theory and*

application (pp. 435–459). Cambridge, MA: MIT Press.

Google Scholar

14. Bjork, R. A. (1994). Memory and metamemory considerations in the training of human beings. In J. Metcalfe & A. Shimamura (Eds.), *Metacognition: Knowing about knowing* (pp. 185–205). Cambridge, MA: MIT Press.

Google Scholar

15. Bjork, R. A., & Bjork, E. L. (1992). A new theory of disuse and an old theory of stimulus fluctuation. *From learning processes to cognitive processes: Essays in honor of William K. Estes, 2*, 35–67.

Google Scholar

16. Bjork, E. L., & Bjork, R. A. (2011). Making things hard on yourself, but in a good way: creating desirable difficulties to enhance learning. *Psychology and the real world: Essays illustrating fundamental contributions to society*, 56–64.

17. Blunt, J. R., & Karpicke, J. D. (2014). Learning with retrieval-based concept mapping. *Journal of Educational Psychology, 106*, 849–858.

Article Google Scholar

18. Boulton, K. (2016). What does cognitive overload look like in the humanities? [Blog post]. Retrieved

from https://educationechochamberuncut.wordpress.com/2016/03/05/what-does-cognitive-overload-look-like-in-the-humanities-kris-boulton-2/. Accessed 25 Dec 2017.

19. Brown, P. C., Roediger, H. L., & McDaniel, M. A. (2014). *Make it stick*. Cambridge, MA: Harvard University Press.

Book Google Scholar

20. Butler, A. C. (2010). Repeated testing produces superior transfer of learning relative to repeated studying. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*, 1118–1133.

PubMed Google Scholar

21. Caplan, J. B., & Madan, C. R. (2016). Word-imageability enhances association-memory by recruiting hippocampal activity. *Journal of Cognitive Neuroscience, 28*, 1522–1538.

PubMed Article Google Scholar

22. Cepeda, N. J., Pashler, H., Vul, E., Wixted, J. T., & Rohrer, D. (2006). Distributed practice in verbal recall tasks: a review and quantitative synthesis. *Psychological Bulletin, 132*, 354–380.

PubMed Article Google Scholar

23. Cepeda, N. J., Vul, E., Rohrer, D., Wixted, J. T., & Pashler, H. (2008). Spacing effects in learning a temporal ridgeline of

optimal retention. *Psychological Science, 19*, 1095–1102.

PubMed Article Google Scholar

24. Chi, M. T., De Leeuw, N., Chiu, M. H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*, 439–477.

Google Scholar

25. Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*, 121–152.

Article Google Scholar

26. CIFE. (2012). No January A level and other changes. Retrieved from http://www.cife.org.uk/cife-general-news/no-january-a-level-and-other-changes/. Accessed 25 Dec 2017.

27. Clark, D. (2016). One book on learning that every teacher, lecturer & trainer should read (7 reasons) [Blog post]. Retrieved from http://donaldclarkplanb.blogspot.com/2016/03/one-book-on-learning-that-every-teacher.html. Accessed 25 Dec 2017.

28. Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review, 3*, 149–210.

Article Google Scholar

29. Class Teaching. (2013). Deep questioning [Blog post]. Retrieved from https://classteaching.wordpress.com/2013/07/12/deep-questioning/. Accessed 25 Dec 2017.

30. Clinton, V., Alibali, M. W., & Nathan, M. J. (2016). Learning about posterior probability: do diagrams and elaborative interrogation help? *The Journal of Experimental Education, 84*, 579–599.

Article Google Scholar

31. Coffield, F., Moseley, D., Hall, E., & Ecclestone, K. (2004). *Learning styles and pedagogy in post-16 learning: a systematic and critical review*. London: Learning & Skills Research Centre.

Google Scholar

32. Cohen, R. L. (1981). On the generality of some memory laws. *Scandinavian Journal of Psychology, 22*, 267–281.

Article Google Scholar

33. Cooper, H. (1989). Synthesis of research on homework. *Educational Leadership, 47*, 85–91.

Google Scholar

34. Corbett, A. T., Reed, S. K., Hoffmann, R., MacLaren, B., & Wagner, A. (2010). Interleaving worked examples and cognitive tutor support for algebraic modeling of problem situations. In *Proceedings of the Thirty-Second*

Annual Meeting of the Cognitive Science Society (pp. 2882–2887).

Google Scholar

35. Cox, D. (2015). No stakes testing – not telling students their results [Blog post]. Retrieved from https://missdcoxblog.wordpress.com/2015/06/06/no-stakes-testing-not-telling-students-their-results/. Accessed 25 Dec 2017.

36. Cox, D. (2016a). Ditch revision. Teach it well [Blog post]. Retrieved from https://missdcoxblog.wordpress.com/2016/01/09/ditch-revision-teach-it-well/. Accessed 25 Dec 2017.

37. Cox, D. (2016b). 'They need to remember this in three years time': spacing & interleaving for the new GCSEs [Blog post]. Retrieved from https://missdcoxblog.wordpress.com/2016/03/25/they-need-to-remember-this-in-three-years-time-spacing-interleaving-for-the-new-gcses/. Accessed 25 Dec 2017.

38. Craik, F. I. (2002). Levels of processing: past, present… future? *Memory, 10*, 305–318.

PubMed Article Google Scholar

39. Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: a framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11*, 671–684.

Article Google Scholar

40. Danan, M. (1992). Reversed subtitling and dual coding theory: new directions for foreign language instruction. *Language Learning, 42*, 497–527.

41. Dettmers, S., Trautwein, U., & Lüdtke, O. (2009). The relationship between homework time and achievement is not universal: evidence from multilevel analyses in 40 countries. *School Effectiveness and School Improvement, 20*, 375–405.

42. Dirkx, K. J., Kester, L., & Kirschner, P. A. (2014). The testing effect for learning principles and procedures from texts. *The Journal of Educational Research, 107*, 357–364.

43. Dunlosky, J. (2013). Strengthening the student toolbox: study strategies to boost learning. *American Educator, 37*(3), 12–21.

44. Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest, 14*, 4–58.

45. Ebbinghaus, H. (1913). Memory (HA Ruger & CE Bussenius, Trans.). *New York: Columbia University, Teachers College. (Original work published 1885)*. Retrieved from http://psychclassics.yorku.ca/Ebbinghaus/memory8.htm. Accessed 25 Dec 2017.

46. Eglington, L. G., & Kang, S. H. (2016). Retrieval practice benefits deductive inference. *Educational Psychology Review*, 1–14.

47. Eitel, A., & Scheiter, K. (2015). Picture or text first? Explaining sequential effects when learning with pictures and text. *Educational Psychology Review, 27*, 153–180.