MEASUREMENT OF TRANSFER OF TRAINING

By Stanley N. Roscoe and Beverly H. Williges

Chapter 16 of:


ABSTRACT

The term transfer of training refers to the degree to which learning one task is facilitated or hindered by the prior or interpolated learning of another. To measure transfer from a flight simulator to an airplane, at least two groups of trainees are required. Speed of learning in an airplane by a group first trained in a simulator is compared with the speed of learning by a control group trained only in the airplane. The various quantitative measures of transfer include “percent transfer,” the ratio of the time or trials saved by the experimental group relative to the control group; “transfer effectiveness,” the ratio of the time or trials saved in the airplane to the time or trials spent in the simulator; and “incremental transfer effectiveness,” the ratio of the incremental saving for each additional increment of time or trials spent in the simulator. Transfer effectiveness is translated to cost effectiveness by factoring in the hourly costs of training in each device.

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ALL learning is based on a foundation of prior learning. *Transfer of training* and, more explicitly, *transfer of learning* are terms that refer to the dependence of new learning on old. In the training of pilots, as in the learning of nonsense syllables or the manual tracking of a crooked course, the efficiency of transfer of old learning to new varies widely, but there is ample experimental evidence that flight training in ground-based aircraft simulators can yield high transfer to the piloting of airplanes (Williams and Flexman 1949a; 1949b; Flexman, Matheny, and Brown 1950; Mahler and Bennett 1950; Flexman, Townsend, and Ornstein 1954; Payne et al. 1954; Wilcoxon, Davy, and Webster 1954; Creelman 1955; Crook 1967; Caro, Isley, and Jolley 1968; 1973; Povenmire and Roscoe 1971; 1973; Caro 1972; Flexman et al. 1972; Jacobs and Roscoe 1975; Finnegan 1977a; 1977b; Lintern and Roscoe 1978).

TRANSFER PARADIGM

Traditionally, measurement of transfer of training deals with the degree to which learning one task is facilitated by the prior or interpolated learning of another. To measure transfer, at least two groups are required. Speed of learning by an experimental group previously trained on another, usually similar, task is compared with the learning performances of a control group having no special previous training. Consider, for example, the hypothetical findings summarized in Exhibit 16.1 in which the transfer from prior study by two experimental groups is evaluated in terms of the relative amounts of tutoring required to pass the same examination.

One group of students devoted an average of 500 hours each to the study of literary German during two years of classwork; a comparable group individually devoted an average of 100 hours to the study of The
EXHIBIT 16.1. Hypothetical transfer data.

key to rapid translation of German by C. V. Pollard. Subsequently, members of both groups required an average of 100 hours of individual tutoring to reach criterion performance in translating scientific German. Members of a control group with no prior study of German required an average of 200 hours of tutoring to meet the same criterion.

Which of the first two groups demonstrated the higher transfer of learning? Clearly the answer based on the traditional measure, percent transfer, does not adequately describe the relative performances of the two hypothetical experimental groups. Nevertheless, since the days of Weber, Fechner, and Volkmann (see Woodworth 1938), investigators of transfer have failed to take proper quantitative account of the amount of prior or interpolated practice contributing to the observed transfer effects. The basic computation is:

\[
\text{Percentage of transfer} = \frac{Y_0 - Y_x}{Y_0} \times 100
\]  

where:

\(Y_0\) = time, trials, or errors required by a control group to reach a performance criterion after zero training units on a prior or interpolated task;

\(Y_x\) = corresponding value for an experimental transfer group having received \(X\) training units on a prior or interpolated task.

Substituting values from Exhibit 16.1,

\[
\frac{200 - 100}{200} \times 100 = 50\%
\]

Each of the two transfer groups in the hypothetical example demonstrated 50 percent transfer despite the fact that one invested 5 hours for every hour invested by the other on prior practice. If time has any value, a meaningful basis for measurement of transfer effectiveness in terms of its cost is essential.

PERCENTAGE OF TRANSFER

Methods of measuring pilot performance during learning and rational bases for evaluating training experiences in terms of their transfer to
operational situations have been slow in emerging. The most frequently used transfer measure has been some form of percentage of transfer that deals with the degree to which learning on one task is facilitated by prior study or practice on another.

Ellis (1965) described three percentage of transfer formulas. The simplest of these is the traditional one given in Equation (1). The second is an expansion of the first by Gagné, Forster, and Crowley (1948) such that percentage of transfer represents a percentage of total possible learning. The result is an absolute transfer scale ranging from zero to 100 percent transfer and most likely comprised of unequal units. The general formula is:

$$\text{Percentage of transfer} = \frac{L_X - L_0}{T - L_0} \times 100$$  \hspace{1cm} (2)

where:

- $L_0 =$ average learning of a control group after zero training units on a prior or interpolated task;
- $L_X =$ average learning of an experimental transfer group after $X$ training units on a prior or interpolated task;
- $T =$ total possible score on the transfer task.

Ellis pointed out that the major difficulty with Equation (2) is that the value of $T$ may be impossible to determine.

The third percentage of transfer formula, proposed by Murdock (1957), has the advantage of yielding a symmetrical transfer curve with definite lower and upper limits of $-100$ percent transfer and $+100$ percent transfer. The formula is:

$$\text{Percentage of transfer} = \frac{Y_0 - Y_X}{Y_0 + Y_X} \times 100$$  \hspace{1cm} (3)

where:

- $Y_0 =$ same as $Y_0$ in Equation (1);
- $Y_X =$ same as $Y_X$ in Equation (1).

All percentage of transfer formulas have a common fault; they fail to consider the amount of practice on the prior task. They ignore the fact that economy of transfer is a negatively decelerated function of amount of prior practice. Because percentage of transfer calculations do not include prior practice, they permit no conclusions about transfer effectiveness. Realistically, however, any training program must be concerned with the transfer economy of a training device or technique.
TRANSFER EFFECTIVENESS

The notion of training to a specified performance criterion in a ground-based simulator, as opposed to administering a given amount of training prior to introducing a student to a transfer task in an airplane, was first made explicit by Williams and Flexman (1949b). More importantly, in the same report they first put forth the notion that ground-based flight trainers, or flight simulators as we know them today, should be evaluated in terms of their "training efficiency." Five years later Williams and Adelson (1954) suggested a mathematical model for assessing the utility of increasingly complex and faithful simulation devices in terms of their training-cost efficiency.

In the summer of 1969 Povenmire and Roscoe (1971) conducted an experiment, discussed in Chapter 13, that allowed the transfer of training from the old AN-T-18 and the new GAT-1 Link trainers to the Piper Cherokee airplane to be expressed in terms of their relative "transfer effectiveness." Soon thereafter, Roscoe (1971; 1972) distinguished between "incremental" and "cumulative" transfer effectiveness; Flexman et al. (1972) reported, in terms of cumulative transfer effectiveness, the detailed results of two previously unpublished experiments conducted in 1950 (at which time the fourth author, Ms. Williges, was in the second grade); and Povenmire and Roscoe (1973) explicitly measured the incremental transfer effectiveness associated with 3, 7, and 11 hours of training in the Link GAT-1 in a private pilot course.

The preceding paragraphs summarize the complete history of the formal study of the transfer effectiveness of ground-based flight trainers to fixed-wing airplanes prior to a study by Jacobs (Jacobs and Roscoe 1975; Jacobs 1976) discussed in Chapter 18. The importance of the transfer effectiveness notion lies in the fact that it provides a basis for an objective assessment of the cost effectiveness of any training device or program in incremental terms. The incremental transfer effectiveness function (ITEF) answers the question of how much time is saved in one training situation as a consequence of each successive increment of training in another, generally less costly, situation.

THE NOTION OF INCREMENTAL TRANSFER

The effectiveness of practice on one task, as reflected by a saving in the subsequent learning of a criterion task, is recognized to be a function of the similarity between tasks, the recency of prior practice, and, in the case of interpolated as opposed to prior practice on the initial task, the distribution of such practice. For reasons beyond comprehension, there has been no recognition in the basic literature on learning of the intuitively obvious fact that the effectiveness of transfer is also a negatively decelerated function of the amount of such practice. Investigators per-
forming experiments in closely related research contexts have brushed against the phenomenon and have noted the relationship but typically have not followed up with theory and systematic scientific inquiry.

For example, at the University of Iowa, Lewis, McAllister, and Adams (1951) and McAllister and Lewis (1951) studied facilitation and interference in psychomotor performance of a manual tracking task as functions of the amounts of prior and interpolated practice on the same basic task with control-display relationships reversed. They found clear evidence of a relationship between amount of practice on one task and its effect on subsequent performance on the other under certain circumstances, but the relationships were less clear in others. Lewis, McAllister, and Adams asserted (p. 247): "There have been no previous investigations of facilitation and interference in motor learning which have any direct bearing on the problem." Furthermore, no subsequent investigation has been found that bears directly on it.

An earlier report from the field of verbal learning also suggests the negatively decelerated nature of transfer effectiveness for successive increments of training. McGeoch (1929) found a negatively decelerated relationship between resistance to retroactive interference from a fixed amount of interpolated practice on one list of nonsense syllables and the amount of prior practice on the criterion list. McGeoch states (p. 258): "The conclusion is clear that, measured in terms of saving score, retroactive inhibition [interference] varies inversely as the number of presentations given the material to be learned. The curve of inhibition plotted against number of learning repetitions shows marked negative acceleration [actually the curve as shown is negatively decelerated]."

The investigation of this subject was extended systematically by Briggs (1957) to include various amounts of interpolated as well as original learning. Briggs confirmed the negatively decelerated relationship McGeoch had observed between amount of original learning and resistance to retroaction and, in addition, found that the strength of retroactive interference bears a negatively accelerated relationship to the amount of interpolated learning. Unfortunately, the transfer effectiveness of successive increments of original learning on interpolated learning cannot be determined because Briggs's experimental design did not include a control group with no pretransfer training as it would have if his object had been to investigate transfer effectiveness.

HYPOTHETICAL RELATIONSHIPS

Now consider another set of hypothetical data presented numerically in Exhibit 16.2 and graphically in Exhibit 16.3. The numbers presented, although hypothetical, are not entirely imaginary. Previous studies of flight training spread over 21 years at the University of Illinois (Williams and Flexman 1949b; Williams and Adelson 1954; Muckler et al. 1959;
EXHIBIT 16.2. Hypothetical data on which curves shown in Exhibit 16.3 are based (Roscoe 1971).

Povenmire and Roscoe (1971) provide fragmentary but directly related evidence supporting the shape of the hypothetical functions presented in Exhibit 16.3, if not the specific values.

Evidence shows, for example, that the first hour of instruction in a ground trainer can save more than one hour in presolo flight training. The fifteenth hour in a ground trainer surely would not; its contribution would be difficult to measure. Convincing inferential evidence indicates that successive presolo hours in a ground trainer yield decreasing increments of saving in presolo flight time, and the same decreasing incremental

EXHIBIT 16.3. Relationships among transfer measures based on hypothetical data for general aviation ground trainers used in a 10-hour flight curriculum (Roscoe 1971).
benefits would be expected for any successively related educational experience.

TRANSFER EFFECTIVENESS FUNCTIONS

The curve that results when the incremental relative savings in learning a criterion task are plotted for successive increments of pretraining or interpolated training on another task is termed the Incremental Transfer Effectiveness Function (ITEF). When the ratios of total savings on the criterion task to total time spent on the prior or interpolated task are plotted, the resulting curve is the Cumulative Transfer Effectiveness Function (CTEF). As shown in Exhibit 16.3, both curves are postulated as being negatively decelerated and, therefore, inversely related to the negatively accelerated curve that expresses conventional percent transfer as a function of amount of training on the prior task.

\[
\text{CTEF} = \frac{Y_0 - Y_X}{X}
\]  

(4)

where:

- \( Y_0 \) = time, trials, or errors required by a control group to reach a performance criterion [corresponds to \( Y_0 \) of Equation (1) where \( X = \) zero for the control group];
- \( Y_X \) = corresponding measure for an experimental transfer group having received \( X \) training units on a prior or interpolated task [same as \( Y_X \) of Equation (1)];
- \( X \) = time, trials, or errors by an experimental transfer group during prior or interpolated practice on another task.

\[
\text{ITEF} = \frac{Y_{X-\Delta X} - Y_X}{\Delta X}
\]  

(5)

where:

- \( Y_{X-\Delta X} \) = time, trials, or errors required to reach a performance criterion by an experimental transfer group having received \( X - \Delta X \) training units on a prior or interpolated task;
- \( Y_X \) = corresponding measure for an experimental transfer group having received \( X \) training units on a prior or interpolated task [same as \( Y_X \) of Equation (1)];
- \( \Delta X \) = incremental unit of time, trials, or errors during prior or interpolated practice on another task.

Using data from Exhibit 16.2, the cumulative transfer effectiveness ratio (CTER) for the experimental group that required 5 hours to master
the criterion task in the airplane, after having received 5 hours of practice in the ground-based trainer, is determined by reference to the performance of the control group that without benefit of practice in the ground-based trainer required an average of 10 hours to master the criterion task in the airplane:

$$\text{CTER}_5 = \frac{Y_0 - Y_5}{5} = \frac{10 - 5}{5} = 1 \text{ hour per hour}$$

The incremental transfer effectiveness ratio (ITER) for the fifth hour of practice in the ground-based trainer is calculated by comparing the performance of the group given 5 hours of practice with that of the group given 1 hour less, or 4 hours. The former required an average of 5 hours to master the criterion task; the latter, 5\(\frac{2}{3}\) hours:

$$\text{ITER}_{5-4} = \frac{Y_{5-1} - Y_5}{5-4} = \frac{5\frac{2}{3} - 5}{1} = \frac{2}{3} \text{ hour per hour}$$

Note that the incremental "unit" of training for which the ITER is computed need not be a unitary amount such as one hour, one trial, or one error. The computations performed on the data given in Exhibit 16.4 illustrate this point. In computing any index of transfer, one should not include the time, trial, or trials during which criterion performance was demonstrated.

It is frequently interesting and occasionally instructive to attempt a reinterpretation of old data in terms of new concepts. By estimating the values of appropriate points on some of the learning curves presented by Lewis, McAllister, and Adams (1951: Fig. 2, p. 250; Fig. 7, p. 257) it is possible, with a straightedge and a little imagination, to extract the set of approximations for trials to criterion and trials saved on a transfer task as a function of the amount of original learning on a related task, as shown in Exhibit 16.4.

By calculating the resulting values for percent transfer and transfer effectiveness shown in Exhibit 16.4 and by plotting them as shown in Exhibit 16.5, we found a set of relationships, based on real data, having

<table>
<thead>
<tr>
<th>Measure</th>
<th>Practice Trials on Initial Task</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Trials to criterion on transfer task</td>
<td>13.5</td>
</tr>
<tr>
<td>Trials saved on transfer task</td>
<td>3.5</td>
</tr>
<tr>
<td>Percent transfer</td>
<td>28</td>
</tr>
<tr>
<td>Cumulative transfer effectiveness ratio</td>
<td>0.35</td>
</tr>
<tr>
<td>Incremental transfer effectiveness ratio</td>
<td>0.35</td>
</tr>
</tbody>
</table>

*EXHIBIT 16.4.* Reinterpretation of data extracted from graphically presented results of Lewis, McAllister, and Adams (1951).
the same general form as the hypothetical curves in Exhibit 16.3. Caution was in order, however, because other less orderly data from the same series of experiments did not offer similar comfort for the incremental transfer hypothesis. The first unequivocal demonstration of the negatively decelerated nature of incremental transfer was provided by Povenmire and Roscoe (1973) in a flight training experiment, the results of which are shown in Exhibit 16.6 and explained in greater detail in Chapter 17.

INCREMERENTIAL COST EFFECTIVENESS

Despite the fact that the evidently decreasing transfer from successive increments of any pretraining had been overlooked by experimental psychologists and educators, the importance of the relative amounts of time invested in various training activities is evident when respective costs per unit are considered. If the cost of instruction in a training airplane is $24 per hour and the corresponding figure for ground training is $16 per hour, a flight student could save money by buying ground-trainer time until the benefit from an additional hour would be less than would be gained from two-thirds of an hour of dual instruction in the airplane.

The legal substitution of 11 hours of ground-trainer time for 11 hours of flight time in the private pilot curriculum by certain schools approved by the Federal Aviation Administration was arrived at on the basis of empirical experience rather than formal experimentation. Nevertheless, the law represents the implicit recognition by the FAA that the CTEF for modern general aviation ground trainers, applied to the routine training
of private pilots, drops below unity at about the eleventh hour. The validity of this legally established value gained support from an experiment by Povenmire and Roscoe (1971, discussed in Chapter 13) in which the saving in flight time in the private pilot curriculum equaled the 11 hours spent in a modern ground trainer.

The observation that the CTEF for a ground trainer drops below unity at a specific hour does not guarantee that the use of the ground trainer is economically justified to that point. The answer to that question depends on the trainer's ITEF and the ratio of costs of an hour in the ground trainer to an hour in the aircraft. The ground trainer might still be yielding significant transfer, but its incremental transfer effectiveness might not be sufficient to be cost effective. As may be inferred from the results of the second experiment by Povenmire and Roscoe, the actual cost-effectiveness crossover point for the GAT-1 as used at the University of Illinois for private pilot training is between the fourth and fifth hours.

Nevertheless, the fact that the ITER has dropped below the cost ratio and has become relatively inefficient does not necessarily indicate that further use of a ground trainer by a given student should be stopped. Many considerations such as aircraft availability, weather, local traffic
congestion, safety, or a requirement to complete a training phase by a given date may make it advantageous to continue use of a ground trainer beyond the cost-effectiveness crossover point.

TRAINING STRATEGY

Incremental transfer effectiveness to this point has been considered as a simple function of time; this is clearly an oversimplification. The effectiveness of any training device or training curriculum depends on how it is used; it is influenced by all the well-known facts concerning conditions favorable and unfavorable to learning. Naturally, transfer effectiveness functions will change accordingly, and for this reason the incremental transfer effectiveness measure may prove to be a highly sensitive experimental tool for studying learning phenomena and optimizing training strategies.

It is evident that the same training device may exhibit different transfer effectiveness functions for different phases of a multiphase curriculum. Although a trainer may have reached a point of relative ineffectiveness for presolo training, the same trainer might be expected to exhibit renewed effectiveness for instrument and crosscountry training phases. Thus for any particular training device a series of negatively decelerated curves will be associated with successive phases or blocks of a training curriculum. Their shape and steepness will vary, and the point at which each drops below the cost-effectiveness cutoff line will help determine the training strategy that will yield the most effective distribution of practice on the various curriculum phases or learning blocks.

ANATOMY OF TRANSFER

The measurement of transfer is a complex business. If the relative effectiveness of transfer for various elements of any training curriculum is to be assessed, a research strategy must be developed to deal with the problem of transfer among the elements. More specifically, simulator training in one flight maneuver transfers not only to its airborne counterpart; it transfers to other similar maneuvers performed either in the simulator or in the airplane, as does training in the airplane itself. Not so obviously, training on one aspect of the overall flight task, say verbal communication, may appear to transfer to another quite different aspect, say motor coordination, simply because the early mastery of the first may thereafter allow the student to concentrate more on the second.

Training strategy may call for a student to master each element or subtask of the flight curriculum before proceeding to the next, either in the ground trainer or in the airplane. At the opposite extreme, the strategy might call for students to master the complete flight curriculum in the ground trainer before undertaking any training in the aircraft.
Depending on the strategy employed, the results most certainly would be quite different both in terms of cumulative transfer effectiveness and the relative transfer effectiveness for individual maneuvers and aspects of performance.

GENERALITY OF APPLICATION

Research findings are basic to the extent that they are generalizable to a broad spectrum of applications. It is postulated that the negatively decelerated nature of incremental transfer effectiveness, as illustrated by the examples given, applies to the relationships among all learning experiences, whether they exhibit positive or negative transfer, and it is predicted that future research will support this generalization. It is our belief that the most useful single measure for the educational strategist is, in the long run, the cost effectiveness of any educational experience.

Thus in the process of training system development, as discussed in Chapter 15, time spent in ground trainers must be justified in terms of savings in flight time in corresponding airplanes; time spent in small, simple airplanes must be justified in terms of relative savings in large, complex airplanes. Similarly, in public education the curricular strategy must take into account the cost effectiveness of each phase of training in terms of relative savings in successively higher and more expensive phases. Finally, for each of us the decision to terminate formal education should be based on an estimate of the diminishing incremental benefits we can expect from each successive unit of educational time or money invested.