Simulation Applications in Training

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The purpose of this document is to give the reader an understanding of: 1) the role of simulation in a training curriculum, 2) how to measure transfer of training from the simulator to the real world, and 3) know the types of simulations and simulators that are being used for training.

1. Role of Simulation in a Training Curriculum

Simulation is a representation of the behavior or characteristics of one system through the use of another system. A simulator is a machine for simulating environmental and other conditions for purposes of training or experimentation. Both simulation and simulators have been used as a part of a training curriculum. A curriculum is a specified, fixed-course of study. It is comprised of lectures, exercises, and simulators and is developed through a process shown in Figure 1.

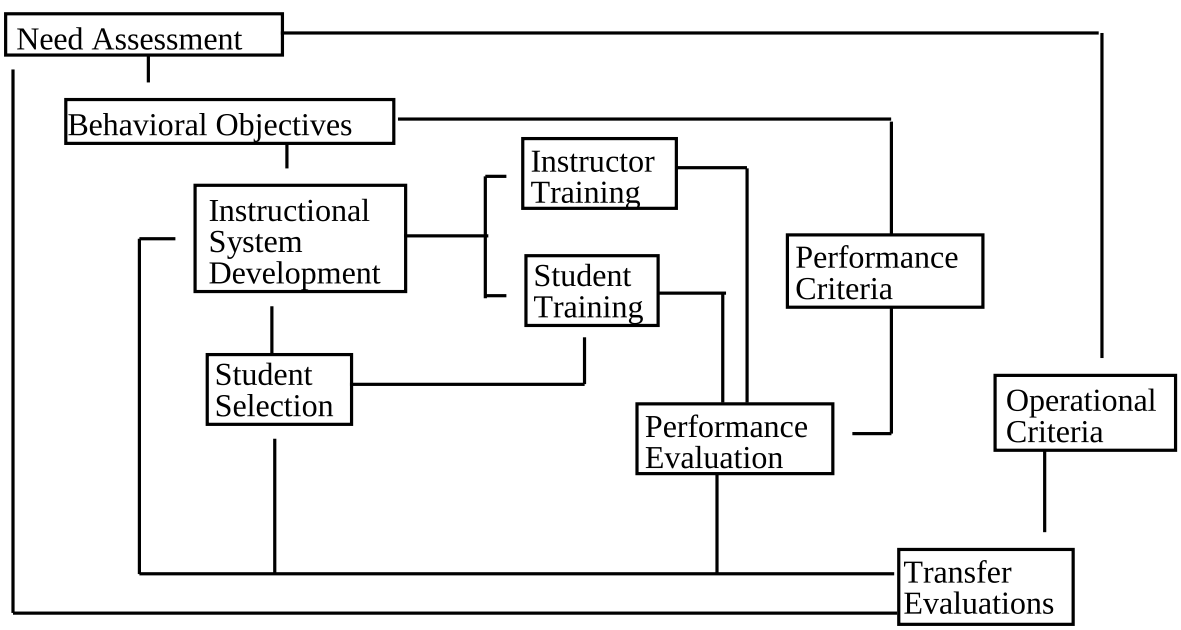

Figure 1. Curriculum Development Process (Roscoe, Jensen, and Gawron, 1980, p. 179)

The process begins with a needs assessment – what behaviors must be trained and to what criteria? How will the performance of both the instructor and the student be evaluated? What are the student selection criteria needed to ensure students pass the training and finally how is the transfer of training measured? If simulation and/or simulators are included in the training curriculum, then the curriculum must be designed to make the best use of these typically high cost assets.

1.1 Curriculum Evaluation

The complete list of criteria for curriculum evaluation and their definitions are presented in the accompanying Table 1. The last component of curriculum evaluation is the use of simulation to design live training exercises. Simulation can identify safety risks as well as how to schedule events to maximize training efficiency. Independently Salas, et al. (in press) developed critical considerations for teamwork and collaboration. These include: cooperation, conflict, coordination, communication, coaching, cognition, composition, context, and culture. See Table 2 in Salas, et al. (in press) for the definitions of these critical considerations.

Table 1. Fundamental Human Factors Criteria for Training

Criterion	Definition
Completeness	The training must include all components of the system that will be experienced by the operator. These components consist of control operation, display symbology and text, all system procedures performed by the operator, and techniques for exploiting imagery.
Clarity	All terminology must be unambiguous. Terms should be easy to understand.
Conciseness	The training must be provided in as few words as possible. Sentence structure should not include a significant amount of parenthetical material or appended phrases.
Consistency	Throughout the training, the same terminology should be unanimously used for the same training component. There should be complete agreement with what has been previously stated in the training.
Compactness	All the training material on a single component should be provided in a single, short training package. The package should include up to a few pages of text in the manual and a few relevant classroom exercises.
Currency	The training material must reflect the current state of the system including: 1. Appearance, placement, labeling, and operation of controls; 2. Wording and meaning of displayed information; 3. Order and actions in procedures; and 4. Application of techniques for exploiting imagery.

Criterion	Definition
Construction	The training modules should build on previous modules and proceed from simple to complex. Further, the presentation should be highly formatted: 1. Place a figure depicting control next to the description of the operation of that control; 2. Place a figure presenting a display next to the discussion of the meaning of the display; 3. Provide procedures in numbered checklists; and 4. Place a figure illustrating the use of an exploitation technique next to a figure of the same imagery, in the same orientation but without the use of the technique, and with a text comparison of the merit of the technique.
Communication	Words used in the training should match the communication skill level, both written and spoken, of the trainees. It should also match the trainees' areas of expertise. For example, drivers should be expected to know the term "volume control" but not the term "hard keys."
Competence	After using the training materials in the designated manner, the trainee should possess the required skills and knowledge to perform the tasks being trained.
Correctness	All material in the curriculum should be correct.

1.2 Performance Evaluation

An important component in the curriculum is determining how well the student meets the performance criteria (see shaded area in Figure 2). Examples of performance criteria are presented in Table 2. The criteria are given by segment, parameter, and target value. There are also five "bins", 4 through 0, of tolerance around the target value. All of these are needed to give the student information on how well he or she must perform each task.

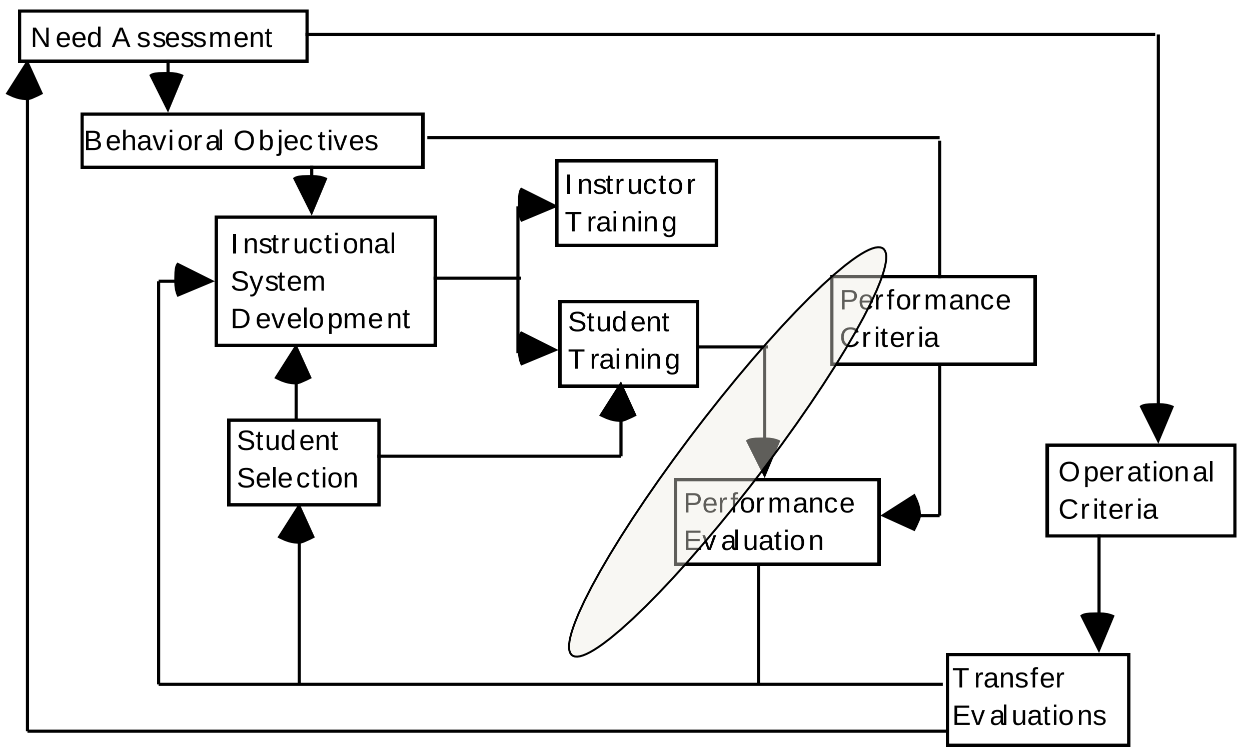

Figure 2. Performance Criteria and Evaluation (Roscoe, Jensen, and Gawron, 1980, p. 179)

Table 2. Performance Criteria for an Instrument Landing System (ILS) Approach (Bailey, Gawron, and Priest, 1994)

ILS Segment		Parameter	Target	4	3	2	1	0
I	Arc Tracking	Altitude	3,000 feet	±50	±100	±150	±200	>200
		Airspeed	170 KIAS	±5	±10	±12.5	±15	>15
		DME	14 nm	±0.25	±0.50	±1.0	±1.5	>1.5
II	Localizer Intercept	Localizer	Centered/0 deg	±0.25	±0.50	±.75	±1.0	>1.5
		Roll Steering	Centered	±0.25	±0.50	±.75	±1.0	>1.0
		Airspeed	160 VIAS	+5.0, -	+10.0, -	+12.5, -	+15.0, -	>+15.0, -
		Altitude	2,500 feet	±50	±100	±150	±200	>200
III	Localizer Tracking	Localizer	Centered/0 deg	±0.25	±0.50	±1.0	±1.5	>1.5
		Roll Steering	Centered/0	±0.25	±0.50	±0.75	±1.0	>1.0
		Altitude	2,500 feet	±50	±100	±150	±200	>200
IV	ILS Tracking	Localizer	Centered	±0.25	±0.50	±1.0	±1.5	>1.5
		Roll Steering	(0 dots)	±0.25	±0.50	±0.75	±1.0	>1.0
		Glideslope	Centered/0	±0.25		±1.0	±1.5	>1.5
		Pitch	0 deg	+0.5, -	+1.0, - 2.0	_1.0, - 2.5	+1.0, -3.0	>+1.0 , -
V	Decision Height	Localizer	Centered/0	±0.25	±0.50	±1.0	±1.5	>1.5
		Roll Steering	Centered/0	±0.25	±0.50	±.1.0	±1.5	>1.5

ILS Segment		Parameter	Target	4	3	2	1	0
		Glideslope	Centered/0	+0.25, -0	+0.5, -	+1.0, -0.5	+1.5, -1.0	>+1.5, -1.0
		Pitch	Centered/0	±0.25	±0.50	±1.0	±1.5	>1.5
		Airspeed	140 KIAS	+5.0, -	+10.0, -	+12.5, -	+15.0, -	>+15.0, -
		Altitude	332 feet	+25, -0	+50, -5	+100, -25	+150, -50	>+150, -50

Another form of performance evaluation is an after action review. In this type of evaluation student performance is not evaluated against quantitative criteria but against behaviors exhibited during a training exercise and the outcome. An example is given in Figure 3. In the example, multiple sensors are placed around the area in which a training exercise is to take place. These sensors collect video data of students during the training exercise and then are merged immediately after to show a complete video record of the student's progress throughout the entire exercise.

Figure 3. Sarnoff Corporation After Action Support Tool

There are two other aspects of performing to criteria that should be assessed: workload and Situational Awareness (SA). Workload is the effort expended by the human operator in accomplishing the imposed performance criteria. There are two types of workload measures that have been used in simulators: performance and subjective estimates. For performance measures of workload, there are again two types. The first is a stand-alone measure. For this type, it is assumed that as workload increases, the additional processing requirements degrade performance. An example is increasing the wind gusts during landing in an aircraft simulator. The second type of performance measure of workload is a secondary task measure. For this type of workload measure, the operator performs the primary task within that task's performance criteria and uses any spare attention or capacity to perform a secondary task; the decrement in performance of secondary task is workload. An example is maintaining control of the aircraft while manually flying an approach in an aircraft simulator while responding to Air Traffic Control calls.

Subjective estimates are ratings given by the students of their own workload. These are easy to administer but may not reflect the true workload. First students may rate only what they **think** they have to do, not all of what they **have** to do. For example, some student pilots do not monitor fuel levels until the fuel warning light comes on. Fuel monitoring is a task that must be done but often is not. Second students may rate their workload low because they do not want to fail the course. High workload tasks, such as driving on ice, are often trained in a simulator for safety reasons.

Situational Awareness (SA) is the "detecting information, processing the information with relevant knowledge to create a mental picture of the current situation, and acting on this picture" (Garner, 1996). There are three types of measures that have been used for SA. The first is subjective estimates either as ratings or as a comparison between perceived and actual situation. One of the early measures of SA was the SA Global Assessment Technique (SAGAT). Using SAGAT, the simulator was stopped at random times and the participant queried on status of elements in the simulation, e.g., distance to the target. A graphic computer program was used for the queries and to compare the perceived and "real" status.

The second type of SA measure is observation. One of the most frequently used observation measure is Crew SA. Expert observers rate crew coordination during a simulator trial and then develop information transfer matrices. Once information transfers have been identified the experts classify decision or nondecision information. This measure requires open and frequent communication among crew members as well as a team of expert observers.

The third type of SA measure is physiological. These include both eye activity (larger pupils, higher SA) and brain activity (theta and delta activity).

2. Transfer of Training

Transfer of training is the application of a skill learned in a simulator to the real world. For example, flight simulators to aircraft, surgical simulators to human patient surgery, or airport checkpoint simulators to baggage inspection. There are three measures of transfer of training. The first, percent transfer of training, is given by the following equation:

$$\frac{Y_0 - Y_X}{Y_0} \times 100$$

where:

Y_0 = time, trials, or errors required by a group of students to reach the performance criterion without training in the simulator

Y_x = time, trials, or errors required by a group of students to reach the performance criterion with x hours in the simulator

However, there are diminishing returns of training in a simulator. Specifically, the first hour in a simulator can save more than one hour in the aircraft. The twentieth hour may not. Aircraft simulators are associated with decreasing increments of actual flight hours saved. These incremental savings for each hour in a simulator are calculated as the Incremental Transfer Effectiveness Ratio (ITER). The ITER equation is:

$$\text{ITER} = \frac{Y_{X-\Delta X} - \Delta X - Y_X}{X}$$

where:

$Y_{x-\Delta x}$ = time, trials, or errors required by a group of students to reach the performance criterion with X - ΔX hours in the simulator

Y_x = time, trials, or errors required by a group of students to reach the performance criterion with X training units in the simulator

ΔX = incremental unit of time, trials, or errors during training in the simulator

Even though students may be learning less per hour in the simulator, they are learning. The cumulative amount of learning is called the Cumulative Transfer Effectiveness Ratio (CTER). The CTER equation is:

$$\text{CTER} = \frac{Y_O - Y_X}{X}$$

where:

Y_0 = time, trials, or errors required by a group of students to reach the performance criterion without training in the simulator

Y_x = time, trials, or errors required by a group of students to reach the performance criterion with x hours in the simulator

X = time, trials, or errors during training in the simulator

An example to compare each of the transfer of training measures is presented in Figure 4. As expected, the percent transfer of training increases across the number of flight hours while the ITER and CTER per hour decreases. These numbers are dependent on the fidelity of the simulator. Transfer of training as a function of fidelity is presented in Figure 5. A honey region is identified in Figure 5. It is bounded by the lowest cost of ownership and operation with no negative transfer. Quantitative definitions of fidelity of simulator features are presented in Table 3 and instructor station features in Table 4. In depth descriptions of motion cues are presented in Table 5. Brown (2010) provides an example of a transfer of training experiment. In the same year, Sparko, Burki-Cohen, and Go (2010) reported that there were no operationally relevant differences in performance of pilots trained in Full Flight Simulators with motion when tested with the motion system on or off. Gawron (2002) compared in-flight performance of airline pilots in 8 airplane upset accident re-enactments. Pilots were able to recover from the windshear upset but not consistently to icing upsets. For a summary of the results see Gawron and Peer (2014). In a more recent study, McLean, Lambeth, and Mavin (2016) reported that the addition of simulation slightly decreased time in the aircraft but significantly increased training time in total.

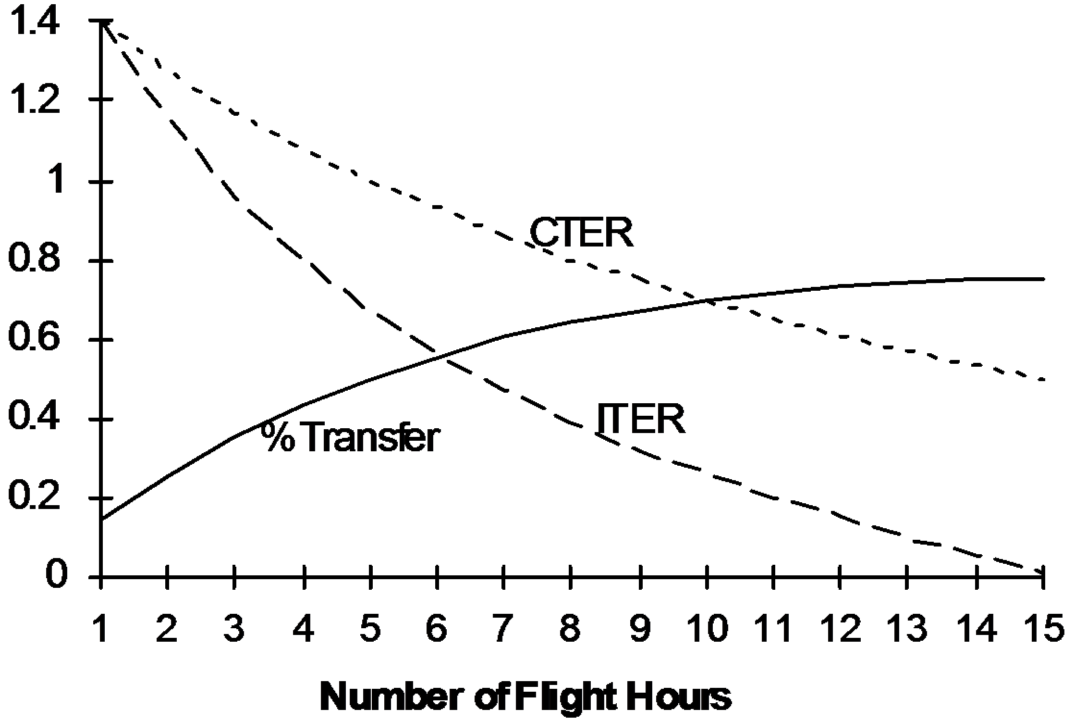

Figure 4. Transfer of Training as a Function of Flight Hours

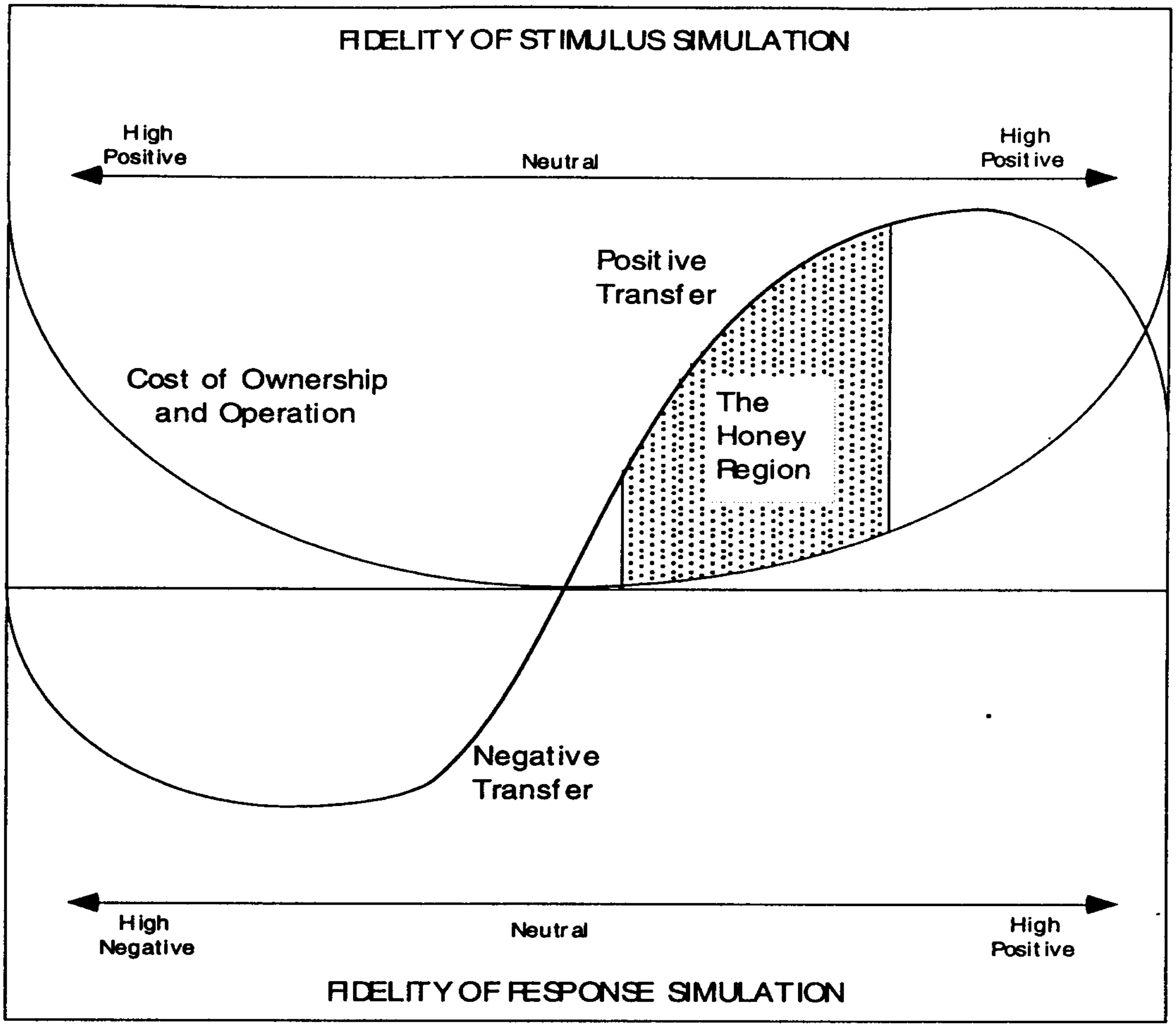

Figure 5. Transfer of Training as a Function of Fidelity (Roscoe, 1980).

Other transfer of training measures have been developed and applied. The first is Trials/Time to Transfer or Trial to Criterion (TTC) which is the number of trials that the student used to reach proficiency (Liu, et al., 2009). The second is the Transfer Effective Ratio (TER):

$$\mathbf{TER} = \frac{Y_0 - Y_X}{\mathbf{X}}$$

(Liu, et al., 2009)

The third measure is first shot performance (fsp):

$$\textbf{fsp} = \frac{\textbf{F - T}}{\textbf{F - L}}$$

where:

F = performance on the first trial in the simulator

T = performance on the first post transfer trial

L = performance on the last trial in the simulator (Liu, et al., 2009)

The fourth measure is Training Retained (TR):

$$\textbf{TR} = \frac{\textbf{C - T}}{\textbf{C - S}}$$

where:

C = performance on the first trial in the real world

T = performance on the first post transfer trial

S = stable performance in the real world (Liu, et al., 2009)

The last measure is the Index of Backward Transfer Formula (β):

$$\beta = \frac{\sum (A_i - S_i)}{N}$$

where:

i = student

N = total number of students

A = mean of student's scores on last two trials in the aircraft

S = student's score during second simulator check ride (Kaempf an Blackwell, 1990)

Hahn (2013) reviewed measures of transfer of training that have been applied to non-flight simulators. Barnard, Veldius, and von Rooij (2001) applied these measures to define 10 types of transfer: positive, negative, far (initial and subsequent tasks differ substantially), near (differ only slightly), low-road (intensive training applied in a new context), high-road (applying already acquired knowledge in new context), general (can be used in tasks other than the original), specific (no transfer expected to other tasks), horizontal (transfer from one to another), and vertical (within a task with growing expertise).

Table 3. Fidelity of Simulator Features (Gawron, Bailey, and Lehman, 1995)

Simulator Features – Motion Cues

Number	Feature	Definition	Fidelity
1.1	**Vibration**	Vibration testing on a "shaker" platform	Stimulus
1.2	**Acceleration**	Centrifuge testing for effects of sustained or transitory accelerations	Stimulus
1.3	**Motion**		
1.3.1	**Low-fidelity**	See Excursion Limits for Fidelity of Motion Cues in Table 5	Stimulus
1.3.2	**Moderate-fidelity**	See Excursion Limits for Fidelity of Motion Cues in Table 5	Stimulus
1.3.3	**High-fidelity**	See Excursion Limits for Fidelity of Motion Cues in Table 5	Stimulus
1.3.4	**Actual flight, no simulation**	An actual flight environment in an aircraft other than the actual crewstation platform	Stimulus
1.4	**Turbulence**		
1.4.1	**None**	No turbulence or turbulence effects	Stimulus
1.4.2	**Simulated**	Effects of turbulence are simulated including: 1) gust and buffet effects on aircraft handling characteristics, 2) vibration of displays and controllers, and 3) vibration of seat and/or restraint system	Stimulus
1.4.3	**Real-world**	Actual turbulence is present and affects aircraft handling characteristics, clarity of displays, response of controllers, and movement of the seat and/or restraint system	Stimulus

Simulator Features – Visual Cues

Number	Feature	Definition	Fidelity
2.1	**Field-of-view size**		
2.1.1	**Narrow field of view**	<45º horizontal, <30º vertical	Stimulus
2.1.2	**Wide field of view**	>45º horizontal, >30_{o} vertical	Stimulus
2.1.3	**Full field of view**	Actual crewstation field of view	Stimulus
2.2	**Visual-scene fidelity**		
2.2.1	**Low detail**	No texturing; <25K multi-faceted polygons per frame	Stimulus
2.2.2	**Moderate detail**	Shading, no texturing; >25K <100K multi-faceted polygons/frame	Stimulus
2.2.3	**High detail**	Texturing, shading; >100K multi-faceted polygons per frame	Stimulus
2.2.4	**Real-world detail**	Actual, real-world visual scene	Stimulus
2.2.5	**Color**	Full color spectrum	Stimulus
2.2.6	**Monochrome**	Monochromatic color	Stimulus
2.3	**Target fidelity**		
2.3.1	**Low detail**	<5 scan lines per target and <5 minutes of arc visual angle	Stimulus
2.3.2	**Moderate detail**	5 -10 scan lines per target & 5 to 10 minutes of arc visual angle	Stimulus
2.3.3	**High detail**	>10 scan lines per target and >10 minutes of visual angle	Stimulus
2.3.4	**Real-world detail**	Real-world sensor images, photographs, or videos	Stimulus
2.3.5	**False-color target**	Varies in color from real-world target by > 1 hue	Stimulus
2.3.6	**Real-color target**	Does not vary in color from real-world target by > 1 hue	Stimulus

Simulator Features – Auditory Cues

Number	Feature	Definition	Fidelity
3.1	**Engine noise**		
3.1.1	**Simulated engine noise**	Actual engine noise from one aircraft or noise produced by a sound mixer	Stimulus
3.1.2	**Actual engine noise**	Actual engine noise or high-quality auditory recording of engine noise as functions of altitude, airspeed, and environmental conditions	Stimulus
3.2	**Vibratory noise**	Low-frequency noise associated with aircraft motion	Stimulus
3.3	**Radio**		
3.3.1	**Simulated radio**	Actual radio equipment is not used	Stimulus
3.3.2	**Real radio**	Actual radio equipment is used	Stimulus
3.4	**Acoustic/airflow noise**		
3.4.1	**Simulated acoustic/airflow noise**	Actual acoustic/airflow noise from one aircraft or noise produced by a sound mixer	Stimulus
3.4.2	**Real acoustic/airflow noise**	Actual acoustic/airflow noise or high-quality auditory recording of acoustic/airflow noise as functions of altitude, airspeed, and environmental conditions	Stimulus

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Simulator Features – Crewstation

Number	Feature	Definition	Fidelity
4.1	**Displays**		
4.1.1	**Static non-operational mockups**	Displays are simulated used non-functional mockups	Stimulus
4.1.2	**Simulated operational displays**	Displays are simulated using functional mockups	Stimulus
4.1.3	**Actual displays**	Actual, functional displays are present	Stimulus
4.2	**Controls**		
4.2.1	**Static mockups**	Controls are simulated using non-functional mockups	Response
4.2.2	**Operational, representative controls**	Controls are simulated using functional mockups	Response
4.2.3	**Actual controls**	Actual, functional controls are present	Response
4.3	**Lighting**		
4.3.1	**Simulated lighting**	Lighting matched in luminance but not spectrum	Stimulus
4.3.2	**Actual lighting**	Actual crewstation lighting present; out-of-crewstation lighting simulated	Stimulus
4.3.3	**Operational conditions**	Actual crewstation lighting present; out-of-crewstation lighting matches actual	Stimulus
4.4	**Seat/Restraints**		
4.4.1	**Non-representative**	Seat does not have actual dimensions or seat restraints	Stimulus

Number	Feature	Definition	Fidelity
4.4.2	**Simulated, representative**	Seat has actual dimension and seat restraints	Stimulus
4.4.3	**Engineering mockup**	Non-functional dimensionally accurate seat and restraints	Stimulus
4.4.4	**Actual seat and restraint**	Actual, functional seat and restraints are present	Stimulus

Simulator Features – Operations

Number	Feature	Definition	Fidelity
5.1	**Flight Stresses**		
5.1.1	**None**	No additional flight stresses are present	Stimulus
5.1.2	**Simulated**	Flight stresses are simulated using gaming techniques	Stimulus
5.1.3	**Real-world**	Real-world flight stresses associated with aircraft responsibility	Stimulus
5.1.4	**Actual**	Real-world flight stresses associated with aircraft responsibility and complete operational conditions	Stimulus
5.2	**Tasks**		
5.2.1	**Synthetic/experimental tasks**	Artificial tasks are imposed	Response
5.2.2	**Actual tasks**	Actual tasks are performed to operational criteria	Response

Table 4. Instructor Support (Pierowicz, J., Robin, J., Gawron, V., Watson, G., Nestor, B., and Murphree, 2002)

Features	**Features to facilitate training/testing**
Tutorial	On-line training for the instructor
Automated measurement	Automatic calculation of time, number of trials, and errors made by each student
Briefing/debriefing	Ability to point out cues and problems
Scenario control	Automatically configure and control the simulator upon instructor selection of conditions
Initial conditions control	Instructor control (a) vehicle configuration, (b) route characteristics, (c) radio/navigation aids, (d) environmental conditions, and (e) vehicle handling characteristics.
Real-time simulation variable control	Control for insertion, removal, and alteration of simulation variables while instructor is in operations. Variables shall include environmental conditions; vehicle configuration, maneuvering, and positioning
Ease of use	Ease of programming, operation, and maintenance
Malfunction control	Instructor can preprogram sequence of abnormal vehicle equipment conditions and/or emergency conditions before or during training session. Time and number of actions required on for instructor to select, alter, and enter malfunctions shall be minimized
Reposition	Capability to position the [simulator] at any point in training
Instructor overview	Provide the instructor with a meaningful depiction of student performance during active training. The presentation of information shall be an easy-to-read, uncluttered, standardized format of the current status of graphical and instructional information
Bird's eye view	Enable instructor see vehicle interactions from above
Freeze	Allow the values of one or more simulator parameters (select system/parameters) to be frozen at any given time within a mission training scenario
Record/replay	Capability to record and reproduce all events, which occurred as a consequence of student, input to the simulator's controls. Recorded student events shall include control

Features	Features to facilitate training/testing
	movements, instrument values, displays, motion cues, visual scenes, sounds and voice communications.
Demonstration	Reproduce all simulated conditions including activation of vehicle cab instruments, indicators, controls, motion system movement, visual display scenes, and communications, as viewed from the cab.
Data storage	Stored data may include information grouped by student, student type and class, the objectives attained, time/attempts to attain the objectives, and conditions under which the objectives were met or not met
Ease of changing scenarios	Ease of instructor to select different scenarios
Tutorial	On-line training for the instructor
Automated measurement	Automatic calculation of time, number of trials, and errors made by each student
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Bird’s eye view	Enable instructor see vehicle interactions from above
Freeze	Allow the values of one or more simulator parameters (select system/parameters) to be frozen at any given time within a mission training scenario
Record/replay	Capability to record and reproduce all events, which occurred as a consequence of student, input to the simulator's controls. Recorded student events shall include control movements, instrument values, displays, motion cues, visual scenes, sounds and voice communications.
Demonstration	Reproduce all simulated conditions including activation of vehicle cab instruments, indicators, controls, motion system movement, visual display scenes, and communications, as viewed from the cab.

Features	**Features to facilitate training/testing**
Data storage	Stored data may include information grouped by student, student type and class, the objectives attained, time/attempts to attain the objectives, and conditions under which the objectives were met or not met
Ease of changing scenarios	Ease of instructor to select different scenarios

Table 5. Excursion Limits for Fidelity of Motion Cues (Gawron, Bailey, and Lehman, 1995)

	Fidelity		
Kinematics	**Low fidelity**	**Medium fidelity**	**High fidelity**
Longitudinal Acceleration	$0.0 < \Delta g_x <\pm 0.5g$	$\pm 0.5 < \Delta g_x <\pm 1.5g$	$\pm 1.5 < \Delta g_x$
Longitudinal Velocity	$0.0 < \Delta v_x <\pm 2.5fps$	$\pm 2.5 < \Delta v_x <\pm 7.5fps$	$\pm 7.5 < \Delta v_x$
Longitudinal Displacement	$0.0 < \Delta x <\pm 2.5ft$	$\pm 2.5 < \Delta x <\pm 7.5ft$	$\pm 7.5 < \Delta x$
Lateral Acceleration	$0.0 < \Delta g_y <\pm 0.5g$	$\pm 0.5 < \Delta g_y <\pm 1.0g$	$\pm 1.0g < \Delta g_y$
Lateral Velocity	$0.0 < \Delta v_y <\pm 2.5fps$	$\pm 2.5 < \Delta v_y <\pm 5.0fps$	$\pm 5.0fps < \Delta v_y$
Lateral Displacement	$0.0 < \Delta y <\pm 2.5ft$	$\pm 2.5 < \Delta y <\pm 5.0ft$	$\pm 5.0ft < \Delta y$
Vertical Acceleration	$0.0 < \Delta g_z <\pm 0.5g$	$\pm 0.5 < \Delta g_z <\pm 1.5g$	$\pm 1.5g < \Delta g_z$
Vertical Velocity	$0.0 < \Delta v_z <\pm 2.5fps$	$\pm 2.5 < \Delta v_z <\pm 7.5fps$	$\pm 7.5fps < \Delta v_z$
Vertical Displacement	$0.0 < \Delta z <\pm 2.5ft$	$\pm 2.5 < \Delta z <\pm 5.5ft$	$\pm 7.5ft < \Delta z$
Pitch Acceleration	$0.0 < \Delta \dot{q} <\pm 0.5r/s^2$	$\pm 0.0 < \Delta \dot{q} <\pm 1.5r/s^2$	$\pm 1.5r/s^2 < \Delta \dot{q}$
Pitch Velocity	$0.0 < \Delta q <\pm 0.5r/s$	$\pm 0.5 < \Delta q <\pm 1.5r/s$	$\pm 1.5r/s < \Delta q$
Pitch Displacement	$0.0 < \Delta \theta <\pm 0.5rad$	$\pm 0.5 < \Delta \theta <\pm 1.5rad$	$\pm 1.5rad < \Delta \theta$
Roll Acceleration	$0.0 < \Delta \dot{p} <\pm 0.5r/s^2$	$\pm 0.5 < \Delta \dot{p} <\pm 1.5r/s^2$	$\pm 1.5r/s^2 < \Delta \dot{p}$
Roll Velocity	$0.0 < \Delta p <\pm 0.5r/s$	$\pm 0.5 < \Delta p <\pm 1.5r/s$	$\pm 1.5r/s < \Delta p$
Roll Displacement	$0.0 < \Delta \phi <\pm 0.5rad$	$\pm 0.5 < \Delta \phi <\pm 1.5rad$	$\pm 1.5rad < \Delta \phi$
Yaw Acceleration	$0.0 < \Delta \dot{r} <\pm 0.5r/s^2$	$\pm 0.5 < \Delta \dot{r} <\pm 1.5r/s^2$	$\pm 1.5r/s^2 < \Delta \dot{r}$
Yaw Velocity	$0.0 < \Delta r <\pm 0.5r/s$	$\pm 0.5 < \Delta r <\pm 1.5r/s$	$\pm 1.5r/s < \Delta r$
Yaw Displacement	$0.0 < \Delta \ddot{Y} < 0.5rad$	$\pm 0.5 < \Delta \ddot{Y} < 1.5rad$	$1.5rad < \Delta \ddot{Y}$

One deviation from stimulus fidelity is Above Real Time Training (ARTT)(Crane and Guckenberger, 2000). In this type of training, time in the simulator is sped up to increase the number of events to which the student responds. Air Force Research Laboratory personnel examined up to 20 times real time to train patterns of behavior to novices. This resulted in enhanced dual- and multi-task performance. This technique has also been applied by NASA to encourage automaticity and reduce pilot workload. Researchers funded by Defence Research and Development Canada reported that one ARTT training session enhanced performance on a simulated flight control task (Donderi, Niall, Fish, and Goldstein, 2012).

In a meta study of transfer of training, Oskarsson, Nahlinder, and Svensson (2010) compared the rated fidelity, presence, feedback, motivation/fun, learning, and effect on reality from soldiers and officers at four simulator sites (Tank-122 simulator, Combat Vehicle 90, active sonar anti-submarine warfare (ASW) simulator, and MCM Wargaming). There were significantly higher ratings for the Tank-122 simulator (motion base and surround visual scene) than the Combat Vehicle 90 (no motion with limited visual scene) or the MCM Wargaming. There were also significantly higher ratings on motivation/fun and feedback compared to fidelity and presence. In another transfer of training meta-analysis, deWinter, Dodou, and Mulder (2012) concluded that higher transfer of training occurs with flight simulator motion than without for flight-naïve students learning to handle external disturbances or condoling vehicles with low dynamic stability.

Another metric that has been used to assess costs associated with training is the efficiency metric (Feldon, 2003). The metric was designed to measure a student's progress toward become an expert in the task being trained. It is based on a three stage model of skill acquisition. Feldon argues that the student's learning must be evaluated on three axes: speed, task efficiency, and mental effort or automaticity.

3. Types of Simulators Used in Training

Simulators can be categorized as either traditional or nontraditional simulators. Each category is described in a separate section below.

3.1 Traditional Types of Simulators Used in Training

Traditional simulators have the following characteristics: 1) a large body of research, 2) standard interfaces and functionality, 3) instructional packages, and 4) technology to enhance processing speed and visuals. There are six traditional types of simulators: 1) static mockups, 2) dynamic mockups, 3) part task simulators, 4) part mission simulators, 5) full mission simulators, and 6) in-flight simulators. Each is described in section below.

3.1.1 Static Mockups

A static mockup is a three-dimensional (3-D) model of a product or system that has no moving parts. Static mockups range in scope from an individual control, such as an airplane control yoke, to an entire vehicle control station. There are three types of materials typically used: 1) foam core is a thin sheet of dense Styrofoam™ (usually 1/8 or 3/16-inch-thick) covered with white paper, 2) wood, and 3) plastic developed using stereolithography which applies 3-dimensional solid Computer Aided Design (CAD) data to build parts from a liquid photopolymer resin that solidifies when exposed to a high-radiance light source. Static mockups are typically used for procedures training. For more information, see Gawron, Dennison, and Biferno (2002).

3.1.2 Dynamic Mockups

A dynamic mockup is a three-dimensional (3-D) model of a product or system that has moving parts which do not have functionality. Dynamic mockups range in scope from an individual control, such as an airplane control yoke, to an entire vehicle control station. There are three types: 1) wood, 2) plastic (again through stereolithography, and 3) hardware to emulate moving parts such as controls and seat restraints. Dynamic mockups are typically used for procedures training, especially emergency procedures training.

3.1.3 Part Task Simulators

Part task simulators simulate a specific aspect of the task for training. Examples include landing an aircraft, navigating a ship under a bridge, and an emergency response in a nuclear power plant. Another good example is the Spatial Disorientation Trainer (www.wylelabs.com). This device trains pilots to recognize and counter the following:

1. Confusion of light sources in night flight conditions (autokinesis)
2. Coriolis illusion
3. Elevator illusion
4. False vertical and horizontal cues
5. Graveyard spin
6. Graveyard spiral
7. Inversion illusion
8. Oculogravic and Oculogyral illusions
9. Somatogravic and Somatogyral illusions
10. The Leans

A similar system, the GYROLAB GL-2000 is being used to train civilian pilots in airplane upset prevention and recovery (http://www.nastarcenter.com/aerospace-training/space/pilots-and-crew/upset-prevention-and-recovery).

3.1.4 Part Mission Simulators

A part mission simulator simulates a specific part of the mission for training. Examples include: 1) finding, lining up, and landing onboard an aircraft carrier and 2) the Joint Fires and Effects Trainer for time sensitive targeting and synchronizing fires with maneuvers. These simulators are typically replicas of the controls and displays needed to complete the part of the mission being trained.

3.1.5 Full Mission Simulators

A full mission simulator simulates all tasks from start to end of mission. For aircraft related missions, these tasks may include landing, takeoff, weapons delivery, night flight, formation flight, and cockpit familiarization in normal, adverse, and emergency situations. These simulators recreate sounds, motion, visual scenes, instrument presentations and all other systems. Vehicle (air or land) simulators represent actual vehicle characteristics based on available operating data and input from experienced operators. Examples of full mission simulators include a King Air Level C aircraft simulator from Frasca International, the CAE Integrated Procedure Trainer, and the National Advanced Driving Simulator.

3.1.6 In-flight Simulators

An in flight simulator is a ground simulator that flies and a test bed aircraft that plays make-believe. It replicates another aircraft's dynamic response with cockpit controller force-versus-position. It also replicates cockpit displays. Finally, there is computer control of all six degrees of freedom including the response to air turbulence. Examples include the Total In-Flight Simulator (TIFS, see Figure 6), the Variable Stability In-Flight Simulation Test Aircraft (VISTA), and two Lears (24 and 25). For more information, see Gawron and Reynolds (1995).

Figure 6. TIFS (NASA photograph)

3.2 Nontraditional Types of Simulators Used in Training

Nontraditional types of simulators used in training have a comparatively smaller body of research, limited standardization in either interface or functionality, and custom built instructional packages. Technologies are being developed to enhance processing speed, visuals, auditory cues, and haptic cues. Examples of nontraditional types of simulators and simulations are listed below:

1. Distributed Mission Trainers
2. Virtual Reality
3. Embedded Training
4. Cell Phones

5. Tablet Computing
6. Gaming
7. Weightlessness Simulators

3.2.1 Distributed Mission Trainers

Distributed Mission Trainers are individual simulators located in different locations that simulate the same environment. For example, a pilot flying a fighter aircraft simulator sees a tank that is being controlled by a soldier in a tank simulator in different location. Distributed Mission Trainers are the current state of the art in training simulation. An example is given by the United States Air Force Research Laboratory (see Figure 7).

Figure 7. Distributed Mission Trainers
(http://www.mesa.afmc.af.mil/learningmanagement.html)

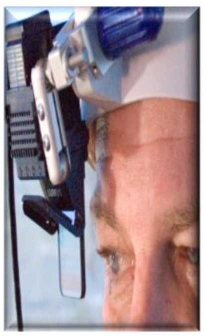
3.2.2 Virtual Reality

Virtual reality (VR) is a computer simulation that enables the user to interact with a virtual environment. Types of VR include:

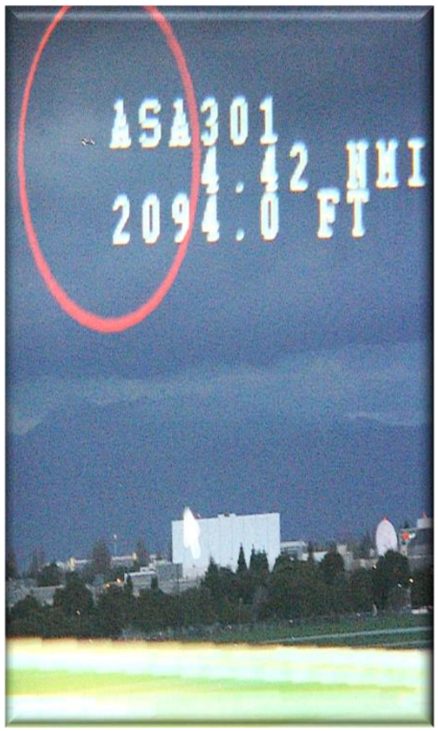
Augmented Reality
Digitally Enhanced Mannequins
Data Glove
Head Mounted Display
Flat World
Virtual Worlds

3.2.2.1 Augmented Reality

Augmented reality overlays computer generated imagery on real imagery. Examples are the Augmented Reality Tower Tools (ARTT) in which aircraft information is projected on top of an aircraft as seen through an Air Traffic Control tower (see Figure 8) and the Augmented Abdominal Surgical System in which imagery of organs are projected on top of an actual patient (see Figure 9). There are even augmented reality applications for iPhones (see Figure 10). Extensive use of this technology is being made in China for training (see a maintenance training example Chang, Fang, and Hu, 2010) and Europe (see Granlund, Smith, and Granlund, 2011).



Monocle



Data block and the circle are projected on aircraft

3-D optical images are projected on top of the actual objects

Figure 8. Augmented Reality Tower Tools (Courtesy: Reisman, NASA)

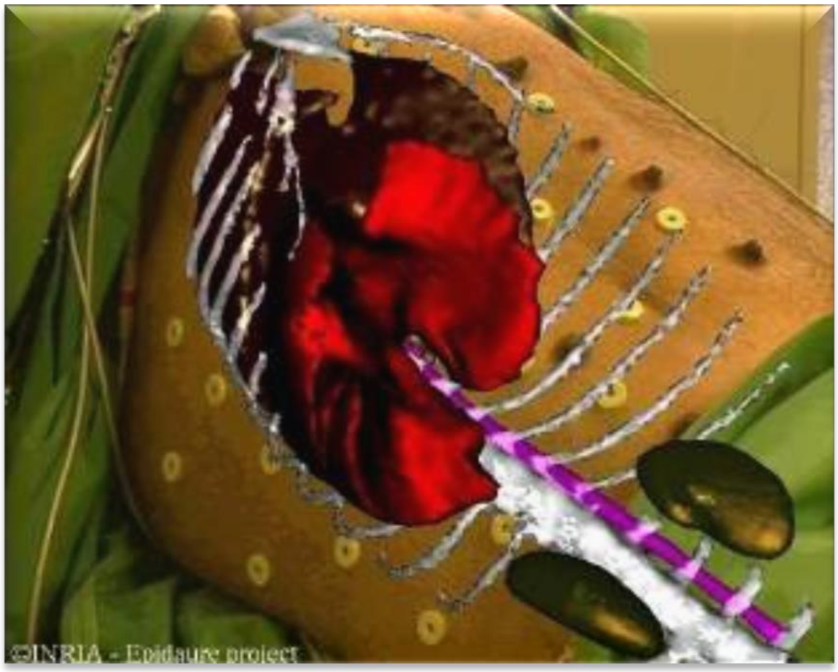


Figure 9. Augmented Abdominal Surgical System (http://www-sop.inria.fr/asclepios/research/images/Augmented_reality_for_abdominal_surgery.jpg)

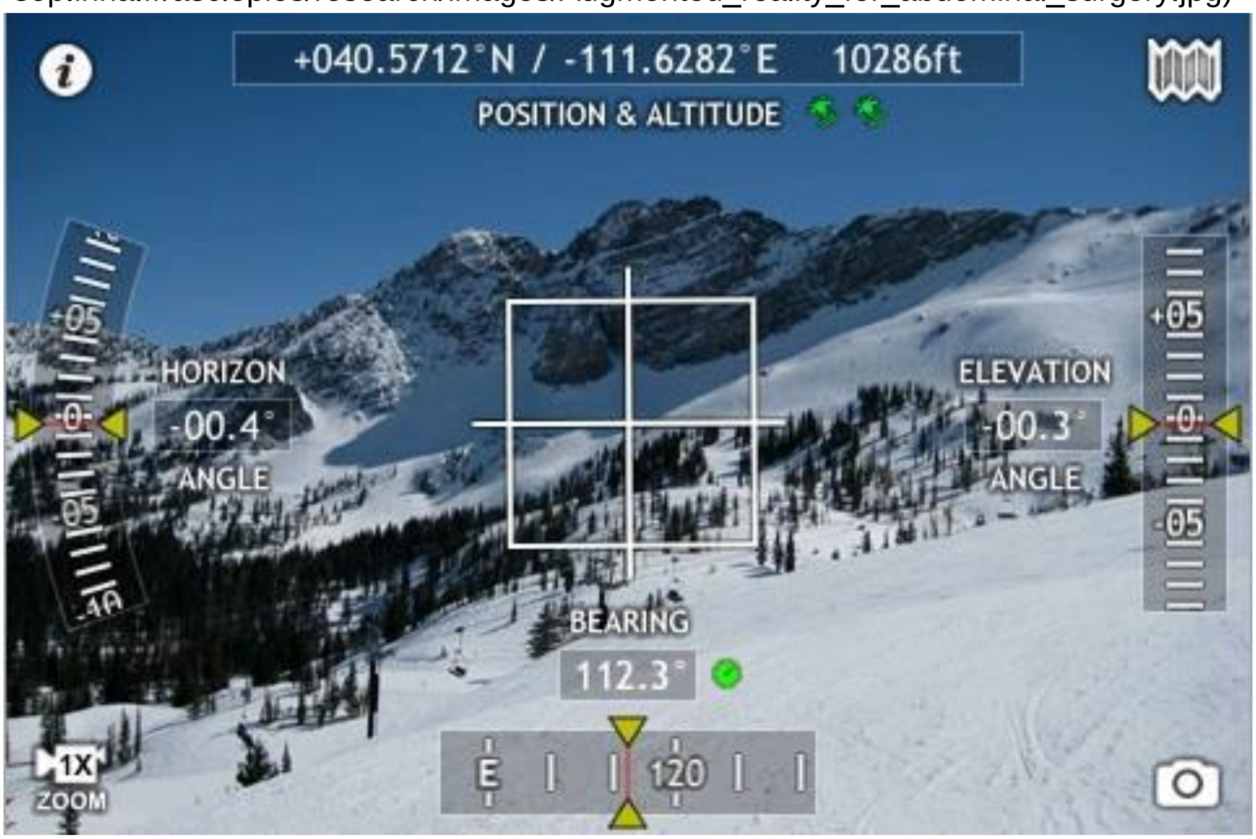


Figure 10. Theodolite Application for iPhones

3.2.2.2 Digitally Enhanced Mannequins

Digitally enhanced mannequins are used to train medical students. An example is iStan which moves, breathes, lives, and dies. iStan is self-contained and wireless (see Figure 11). It has simulated body fluids with articulated motion. iStan was featured on the television program, “Grey's Anatomy”. The original episode aired on November 6 at 9 p.m. EST 2008 on ABC.

Figure 11. iStan Photo courtesy of CAE Healthcare

3.2.2.3 Data Glove

The DataGlove is worn on the trainee’s hand and has an array of sensors that enables the trainee to manipulate virtual controls that are presented in an immersive 3-D visualization environment. An example is presented in Figure 12 which shows DataGloves on an Air Force pilot manipulating a virtual version of the cockpit displays (also shown in Figure 12) that are presented to the subject through the use of a head-mounted display system.

Figure 12 DataGloves and Head Mounted Display
(http://www.mesa.afmc.af.mil/learningmanagement.html)

3.2.2.4 Head Mounted Display

Head Mounted Displays provide visual imagery to the trainee. In Figure 12 above, the pilot sees a cockpit and out-the-window views through the use of a head mounted display. In Figure 13, a soldier in a sterile room sees a simulated road, tanks, and potential terrorists as well as the end of his rifle.

Figure 13. Virtual Warrior (http://www.gdc4s.com/content/detail.cfm?item=d3ae855e-74ab-4af0-8c56-abad8be8ea0f&page=6)

3.2.2.5 Flat World

Flat World is a training system developed and used by the United States Army Program Executive Office (PEO) Simulation, Training and Instrumentation (STRI) To provide solid objects in the environment, Flat World projects virtual images on top of movable blank walls similar to flats in a theater (see Figure 14). In Figure 15, two digital flats with physical window and door props create an immersive environment for training. In Figure 16, stereoscopic graphics are used to provide a compelling sense of depth. Virtual humans have been embedded in the Flat World such as the shooter in Figure 16.

Figure 14. Flat World Mix of Imagery on Flats and Actual Props

Figure 15. Flat World

Figure 16. Flat World Stereoscopic Graphics

3.2.2.6 Virtual Worlds

Virtual worlds are software systems that provide 3D visualizations of environments. Examples include Second Life and OpenSim. Second Life is a free 3D virtual world where users can socialize, connect and create using free voice and text chat (http://secondlife.com). It is being used by the United States Navy to train command and control (http://www.navy.mil/search/display.asp?story_id=40755). Another example is the Canadian Border Crossing project (see Figure 17). In 2008, Canada's Loyalist College launched a virtual training program in Second Life for Canadian border-crossing officers. The immersive simulation is designed to help officers more quickly master complex procedure and refine human skills and real-time reasoning through role-play interaction. For more information, contact Ken Hudson, Managing Director, Virtual World Design Centre, Loyalist College. For a review of how immersive virtual worlds, including Second Life, are used in education settings from kindergarten to graduate school see Hew and Cheung (2010). Allison, et al. (2010) recommend OpenSim for educational use rather than Second Life because OpenSim supports self-hosting. Note for manual tasks, Chen, Kimmel, Bartholomew, Ponto, Gleicher, and Radwin (2014) reported decreased accuracy and increased time than when performing the same task with physical objects.

Figure 17. Canadian Border Crossing in Second Life (https://blogs.secondlife.com/community/learninginworld/blog/2009/07/10/case-study-loyalist-college-massively-improves-test-scores-and-training-outcomes-using-second-life)

For a description of virtual humans, see http://ict.usc.edu/.

3.2.3 Embedded Training

Embedded training is designed to be built into or added onto operational systems to enhance and maintain the skill proficiency necessary to operate and maintain that equipment. It enables training delivery to operators using their own equipment while in the field or at home station. It enhances or maintains skill proficiency by enabling soldiers to train using their operational equipment.

3.2.4 Cell Phones

The Army Acquisition Command's Program Executive Office for Simulation, Training and Instrumentation has developed training applications on cell phones. These were developed primarily for remote military units abroad. Current training applications are for maintenance technicians for weapons and aircraft, riflery students (see Dietel, et al., 2012), and mission planners. Mission planners navigate with arrows and zoom functions through 3-D, computer-aided-design maps of cities and buildings. Leung and Chan (2003) developed a framework for mobile learning. The framework has four components: 1) mobile learning applications, 2) mobile user infrastructure, 3) mobile protocol, and 4) mobile network infrastructure. An alternative framework, one designed for under-resourced schools, is described in Kim, et al. (2011). That framework was applied and evaluated in rural India. Naismith, et al. (2004) identified issues with use of mobile technologies for learning: 1) using contextual data will reduce the learner's privacy, 2) mobility allows the student to "escape" the instructor and the curriculum, 3) there is no effective method to measure learning over long periods of time, 4) student may perceive that social networks may be impacted, and 5) students want to control their personal technology. Finally, Seol, Sharp, and Kim (20130) reported that students (4th and 5th graders) using a mobile phone to create questions were very satisfied with the capability to ask questions and to share these questions with peers.

3.2.5 Tablet Computing

Johnson, et al. (2013) have predicted that tablet computing will have widespread adoption in higher education. These devices have already been applied in military settings. For example, the Future Combat System has used an iPad for providing procedures training. Further, Banister et al. (2009) identified iPad uses in K-12 for classroom media, notes, clock, calculator, maps, weather, and internet access. They also describe Web Apps for Early Childhood Education – PreSchool Adventures, At the Zoo, ABC Letters, and iDoodle.

3.2.6 Gaming

The use of games to train is not new. As early as the 6th century AD, a two-person strategy game, Chaturanga, was used in India to train for war. The game was adapted by the Persians in the 7th century and named Shatranj. Both of these were very much like chess. A later war game, Kriegsspiel, was developed in 1812 to train officers in the Prussian Army. It used a physical table on which was overlaid terrain and game pieces. An impartial third party observer evaluated each move. The game was modified for use by the United States military in 1880. Look up tables were used to determine fatality rates based on type of weapon, range, etc. (see Livermore, 1879). War gaming became a critical component in training at the Navy War College. Eventually mathematical formulas replaced physical game boards. The formulas evolved into the war game models of today (Allen, 1987; Moroney and Lilienthal, 2009).

Currently video games are used to train personnel. One example is Canon and Cisco using video games to teach technical skills such as equipment repair and network maintenance. Another is e=mz2, a video game developed for sales people to trying to win over a client. Other example includes games developed for the United States Army to train urban combat and stability operations. The most successful American Army game to date was begun as a recruiting tool that later was used to train tactics. Another example is the Virtual Air Traffic Simulation Network (VATSIM) (see http://www.vatsim.net). It has over 100,000 players flying in simulated air traffic environments around the world. Games have the advantages of being efficient and addictive. Keebler, Jentsch, and Schuster (2014) reported that individuals with high video game experience out performed individuals with little video game experience. The task was combat identification. For education, digital games are being used extensively in kindergarten through high school to teach "critical 21st century skills" (http://glasslabgames.org/). However, in a review of the effectiveness, Young, et al. (2012) reported some positive effects on language learning, history, and physical education (exergames) but no positive effects on science and math learning. Weiss, Kramarski, and Talis (2006) reported that kindergarten students taught with multimedia in cooperative learning or with multimedia in individual learning did better in math than students without either type of training.

Using similar technology, hands on virtual labs are becoming prevalent. One example is the Computer Emergency Response Team (CERT) Simulation, Training, and Exercise Platform (STEPfwd) (https://stepfwd.cert.org/vte.lms.web). Tang, et al. (2012) describe a game, Sustain City, for undergraduate level training of science and engineering. Hiskins, et al., (2011) describe virtual simulation to train high school students to design electric cars. Basu, et al. (2013) described an Enactment or E-World, a multi-agent simulation, to teach science to high school students. Another example is MIT's Open Courseware (http://ocw.mit.edu/index.htm). Moreno-Ger (2009) described several low-cost platforms for educational game development.

Johnson et al. (2013) predict that such massively open online courses (e.g., Coursera, edX, and Udacity) will continue to grow in popularity. Picciano, et al. (2012) identified concerns with the quality of instruction, policies for funding such courses, and attendance requirements. Brown and Green (2012) provide an overview of the technology for students as well as instructors. Eshet-Alkalai (2010) identified the challenges for providing effective instructional technologies. Finally, Carnahan (2012) identified the problem of explosive growth in online learning but very little research to assess its effectiveness. To address this problem, he compared learning and satisfaction of seven grade science presented in live virtual lessons, simulated asynchronous lessons, and a traditional classroom lesson. All were provided by the same instructor and all covered the same material. Although there were no significant differences in achievement among the presentation types the highest satisfaction was associated with the virtual classroom. In contrast D'Angelo, et al. (2013) concluded from a meta-analysis of 40 studies that computer-based interactive simulations provided improved training than similar instruction without the simulations.

3.2.7 Weightlessness Simulators

Simulators do not need to be ground-based. For example, NASA has used aircraft to provide parabolic flights to simulate weightlessness. Each parabola takes 10 miles of airspace and provides weightlessness for one minute. For more information, see http://www.gozerog.com/.

Simulators do not have to be mechanical or have any associated software. Weightlessness is also simulated in the Neutral Buoyancy Laboratory (NBL) in the Sonny Carter Training Facility at NASA Johnson. It is the largest indoor pool of water in the world and contains full-sized mock-ups of the Space Shuttle cargo bay, flight payloads, and the International Space Station. Astronauts perform simulated Extra-vehicular activity (EVA) tasks.

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