PERGAMON

Computers in Human Behavior 18 (2002) 773–782

Computers in
Human Behavior

www.elsevier.com/locate/comphumbeh

Developing competency-based methods for near-real-time air combat problem solving assessment☆

Winston Bennett Jr.*, Brian T. Schreiber, Dee H. Andrews

Air Force Research Laboratory, Warfighter Training Research Division, 6030 South Kent Street, Mesa, AZ 85212-6061, USA

Abstract

Air combat scenarios present unique problems where the solution is not obvious. An advanced networked simulation environment can be used to train high-level cognitive air combat skills such as problem solving. A problem in the development of principled and construct oriented assessment is related to determining the level of specificity of the assessment. We present a detailed discussion of the definition of critical competencies associated with combat mission problem solving performance, and we describe our approach to develop and implement an embedded performance assessment system that maps outcomes to these competencies. Finally, we discuss the implications for our approach for comprehensive assessment and discuss our goals for an evaluation of the competency-based approach to assessment.

1. Introduction

Air-to-air combat typically involves a flight of multiple friendly aircraft engaging multiple adversary aircraft at beyond visual ranges (BVR). United States Air Force (USAF) air combat pilots extensively train to learn; aircraft systems, emergency procedures, tactics, air combat jargon, weapons capabilities, adversary capabilities, and rules of engagement (ROE). A goal of this training is to have these knowledges and skills become automatized in the classroom and simulation environments so that wartime implementation of these knowledges/skills is second nature.

☆ The views expressed in this paper are those of the authors and do not necessarily reflect an official position of the organization with which they are affiliated.

* Corresponding author.

0747-5632/02/$ - see front matter
PII: S0747-5632(02)00030-4

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
NOV 2002

2. REPORT TYPE
Journal Article

3. DATES COVERED
00-01-2001 to 00-10-2002

4. TITLE AND SUBTITLE
Developing Competency-based Methods for Near-real-time Air Combat Problem Solving Assessment

5a. CONTRACT NUMBER
F33615-97-D-5000

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)
Winston Bennett Jr; Brian Schreiber; Dee Andrews

5d. PROJECT NUMBER
1123

5e. TASK NUMBER
AS

5f. WORK UNIT NUMBER
1123AS08

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/RHA,Warfighter Readiness Research Division,6030 South Kent Street,Mesa,AZ,85212-6061

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL; AFRL/RHA

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/RHA, Warfighter Readiness Research Division, 6030 South Kent Street, Mesa, AZ, 85212-6061

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL; AFRL/RHA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RH-AZ-PR-2002-0003

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Published in Computers in Human Behavior 18(6), 773-82 (2002)

14. ABSTRACT
Air combat scenarios present unique problems where the solution is not obvious. An advanced networked simulation environment can be used to train high-level cognitive air combat skills such as problem solving. A problem in the development of principled and construct oriented assessment is related to determining the level of specificity of the assessment. We present a detailed discussion of the definition of critical competencies associated with combat mission problem solving performance, and we describe our approach to develop and implement an embedded performance assessment system that maps outcomes to these competencies. Finally, we discuss the implications for our approach for comprehensive assessment and discuss our goals for an evaluation of the competency-based approach to assessment.

15. SUBJECT TERMS
Competency-based methods; Near-real time; Air combat; Problem solving; Networked simulation; Simulation-based training; Simulation environments; Air combat skills; Performance assessment systems;

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Public Release**	**10**	

However, this does not necessarily fully prepare those pilots for the unique problems air combat engagements pose. The number of adversary aircraft, types of aircraft, inter-aircraft geometries (i.e., spatial relationship among relevant aircraft), political influences, and pilot skill differ for each air combat engagement. Therefore, every engagement presents a unique problem solving challenge. Working within each individual's competencies and together as a cohesive unit, the pilots must problem-solve these engagements. "Problem solving is cognitive processing directed at achieving a goal when no solution method is obvious to the problem solver" (O'Neil, 1999). These air combat knowledges and skills in—stark contrast to the classroom, stand-alone simulator, or other more mundane training environment—must be combined with other skills and team members in a dynamic, hostile, time-critical environment to solve a complex problem where the goal is to protect friendly assets and eliminate hostile forces, but the solution is not always obvious.

The USAF conducts training exercises such as "Red Flag" using flying aircraft to specifically provide air combat pilots with an opportunity to practice these higher-level cognitive processing skills. However, these exercises frequently require more than a half dozen real planes to fly in a restricted area with a host of safety regulations affecting the realism. Since such opportunities are scarce and limiting because safety and security restrictions prevent pilots from performing as they would in actual combat, it is desirable to have environments where higher order cognitive problem-solving skills can be trained and measured. A realistic, networked simulation environment could afford these opportunities to train and measure higher order cognitive air combat skills.

Distributed mission training (DMT) is a revolutionary training environment composed of real (live aircraft), virtual (manned aircraft simulators), and constructive systems (computer generated forces) that allow aircrew members to train both individually and collectively (Carroll, 1999). The DMT environment is based on a wide area network of individual cockpits and visual systems that permits interactive training as single aircraft and multiple aircraft. DMT provides a comprehensive environment of simulation technology in which information is dynamically shared and used among a group of individuals engaged in real-time training scenarios (Carroll, 1999). DMT allows multiple players at multiple sites to engage in training scenarios ranging from individual and team participation up to full theater-level (i.e. multi-team, multi-force) battles. Additionally, computer-generated, or constructive, forces can be used to substantially enhance the training scenario. By combining simulation systems through computer networking, multiple operators from different military platforms (e.g. command and control centers, aircraft, ships, tanks) can all train together, adding to the fidelity. Real-time simulation systems such as DMT allow nearly unlimited training opportunities for small or large-scale forces from their own location or a deployed training site.

Virtual environments such as DMT offer researchers the opportunity to manipulate key characteristics of the training environment to promote learning and mastery of complex interdependent tasks (Crane, Robbins, & Bennett, 2000), significantly improving the capability to train at the mission and team level (Crane, 1999). As part of our research program, we are attempting to address a number of challenges and needs associated with both the development and evaluation of DMT as a high-fidelity virtual environment for training and performance assessment. Three specific areas are of particular interest in our training research program. First, developing and validating methods to identify and define mission and training requirements for individuals and teams. Second, developing methods for linking requirements to instructional strategies and principles that can be embedded in realistic training scenarios within the training environment. Third, evaluating the impact of instruction on addressing the requirements through in-training and field performance assessment.

A major problem in the development of principled and construct oriented assessment is related to determining the level of specificity of the assessment. A second problem is developing outcome measures that are both construct oriented and that permit near-real time assessment for diagnosis and remediation.

With respect to the first problem, some researchers have made a move towards examination of competencies, which may differ for individuals and teams (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995). Team competencies can be divided into team-specific and task-specific competencies. Team-specific competencies may only apply to a particular team, yet encompass all tasks the team performs. Task-specific competencies may only apply to certain tasks. Applied to aircrew individual or team training performance, these competencies become Mission Essential Competencies or MECs (Colegrove & Alliger, 2002). Mission Essential Competencies are higher-order individual, team, and inter-team competencies that a fully prepared pilot, crew or flight requires for successful mission completion. For example, for "Air Superiority" (this mission assures that friendly forces have dominant control of the skies), the Engagement Phase MEC reads: *Employs ordnance against valid hostile targets and/or denies enemy weapons in accordance with stated mission objectives.* Each MEC is further defined by identifying a purpose, and a beginning and ending point. The MEC framework also includes some (more general) supporting competencies, and lists of knowledge and skills. In addition, a list of experiences through which these knowledge, skills, and competencies can be learned has also been generated. Mission Essential Competencies are not abstract knowledge or general skills. They are demonstrated, to a degree of competency, in the context of an actual mission or high-fidelity simulated mission (Colegrove & Alliger, 2002). Individual and team competencies are critical for successful missions in a real combat environment.

Using the MECs as the guide, DMT enables researchers to perform systematic scenario development and performance assessment to identify deficient competencies and subsequently train our warfighters in those deficiencies before they head off for battle. Our approach is based on recommendations made by Cannon-Bowers and Bell (1997) regarding the need for knowledge-rich, high-fidelity environments to foster complex skill acquisition.

Different levels of detail have emerged during our Mission Essential Competency development. High-level information summarizes what we have called Mission Essential competencies. Table 1 shows the MECs for very top level training objectives associated with activities such as finding the target, fixing it in terms of its exact location and direction, tracking it to ensure you know where its going, targeting the

Table 1
Top level training objectives by mission essential competency linkage

	[redacted]						
MEC **Tng Obj**	**Organize**	**Detect**	**Intercept / Target**	**Engage**	**Follow-on**	**Orient**	**Trigger**
[redacted]							
Find		X					X
[redacted]							
Track			X			X	X
[redacted]							
Engage				X		X	X
[redacted]							

entity, engaging the target and assessing the outcome of the chain of activities. This sequence of activities is at the heart of solving every air-to-air engagement.

We have also discovered that there is a need for a more detailed description and decomposition to fully describe the Mission Essential Competencies, and to prepare for further analyses based on the Mission Essential Competencies. Specifically, personnel that exhibit high levels of proficiency in a Mission Essential Competency are also proficient in a series of sub-competencies that support the Mission Essential Competency. These supporting competencies are sets of high-level skills, many of which are strongly linked to the pilot's ability to problem-solve. Communication, adaptability (e.g. gameplan, reactions, intercepts), weapons engagement zone (e.g. weapons employment), and decision-making are all examples of problem solving-related supporting competencies and will be the focus of the data reported here. Some supporting competencies are applicable across all Mission Essential Competencies, and others are applicable for only one or two Mission Essential Competencies. Supporting competencies can be broken down even further into knowledge and skills (e.g. switchology). A variety of knowledge and skill requirements are necessary in attaining a supporting competency (Colegrove & Alliger, 2002).

1.1. Syllabus and scenario development

We have applied the matrix shown in Table 1 to developing a comprehensive syllabus for preparing USAF Fighter Weapons School candidates for the school. After a broad based needs assessment was completed, we determined that there is a significant need for principled instruction focus on specific objectives and providing tactically relevant experiences for pilots to prepare them for their school experience. As researchers, we feel that DMT offers high-fidelity opportunities not available in the current operational environment especially in developing problem-solving skills, but also in terms of the sheer number of opportunities for focused experience in high threat, multiple aircraft situations. Moreover, opportunities for dedicated mission planning, execution, analysis and continuous, focused training and practice in a controlled training environment don't exist in the real world.

Together with previous team training research conducted by the Army (Alluisi, 1991), Navy (Fowlkes et al., 1994; Dwyer, Oser, & Fowlkes, 1995), and Air Force (Houck, Thomas, & Bell, 1991), we are designing DMT scenarios that are tied to both this legacy research foundation and new innovations such as mission essential competencies. For the Fighter Weapons School syllabus, specific learning objectives have been identified and missions have been designed to focus on a number of supporting competency objectives within the context of individual and team capabilities enhancement, of which the following directly relate to problem-solving skills and are critical to the higher level MECs presented in Table 1:

- Engagement Decision;
- Tactics to Intercept and Destroy Enemy Aircraft;
- Radar Operations;
- Weapons Employment;
- Judgment;
- Gameplan; and
- Communication.

1.2. Designing scenario trigger events for training, research, and mission success

Once specific objectives have been identified, specialized mission scripts and trigger events can be developed. A trigger event is defined as the action of a controlled entity within a DMT exercise that is designed to elicit a specific response from a trainee. A trigger event, properly designed, greatly enhances the sensitivity to which certain problem solving supporting competencies can be addressed and will lead to less noise in the measurement system assessing that competency.

Controlled entities are most typically computer-generated forces whose actions are programmed by instructors. The actions of computer-generated forces are therefore programmed to be tactically valid and to trigger behaviors from the trainee that fulfill training objectives. For example, computer-generated enemy aircraft can be programmed to present different problems for each of the following the objectives: developing and evaluating targeting, tactics and game plans and using appropriate radar operation procedures and tactical geometry. Specific trigger events can be arranged to provide different and more complex presentations on successive engagements. In one example scenario, enemy forces may enter the engagement as a single group, in two groups separated in range, as two groups separated in horizontal distribution, as two groups separated in altitude, or as a group of three at medium altitude followed by a single, high, fast flying enemy aircraft. In each case, the trainee must use their own aircraft's radar and effectively communicate with the other fighters and airborne air traffic controllers to ensure that all threats are found, fixed, tracked, targeted, engaged and either destroyed or made to leave the area of interest.

1.3. Identifying and linking critical behaviors

Given training objectives and mission scenarios, instructional designers work with subject matter experts to identify critical behaviors that should unfold after a trigger event. These behaviors demonstrate to the instructor whether the trainee has learned the skills required to meet those objectives. Tying scenario events to training objectives and specific trainee behaviors provides the basis for instructor evaluations of team or individual performance. The instructor knows for any given moment in a scenario what objectives are being trained, what trigger events are about to occur, and what behaviors are critical to mission success.

The ultimate question for most training programs is how the training affects actual on-the-job performance (Bennett & Arthur, 1997). For military training programs, this is often a difficult question to answer since most of the current military operations involve peacetime missions. Aircrew members do not always have an environment where transfer of training can be immediately measured. Moreover, when they do get to fly operationally they do not routinely have opportunities to perform the tasks as they were trained in an environment such as DMT. For example, if a training objective in DMT is to provide a flight leader with experience leading a four-aircraft team of fighter aircraft into combat against six adversary aircraft, we can train and evaluate the objective in DMT quite easily. Once the flight leader returns to his/her home unit, however, getting 10 aircraft ready for the same type of training or for a field evaluation is both expensive and impractical in today's logistically constrained environment.

However, because military aircrew training programs are well-structured and occur throughout the career of an aircrew member, it is still possible to collect data on the effectiveness of the training program in changing the behavior that is directly relevant. That is, training evaluation using a DMT system can examine the extent to which we have had an effect on the variables that are ultimately of most interest to us. For DMT, the important question is to what extent does virtual training improve "live-fly" performance. Some examples include the number of training events that have to be repeated, instructor's rating of individual performance, and graduation rate for the next formal training program. An additional way to demonstrate transfer is to develop in-training transfer tasks that are representative of the type of tasks that we would expect to see in combat flying environments.

DMT training research is focusing on extending team process and performance research by using high fidelity simulations both as training instances and as work sample performance tests. Using the simulations in this way requires that very specific information about the operational performance environment be obtained. Therefore, new methods for capturing critical information at both a taskwork and teamwork level must be developed.

2. Methods

2.1. Participants

Eleven teams of pilots have participated in our USAF Weapons School syllabus. The USAF Weapons School is the "graduate school" for Air Force fighter pilots. These teams generally consisted of four pilots (one for each of the four F-16 simulators), an instructor pilot, and an air weapons controller. Mean F-16 flight hours in the aircraft across all pilot participants was 1269 h.

2.2. General procedure

Visiting F-16 pilots arrived early Monday morning for 5 days of training research. They were briefed on procedures and objectives before beginning a 3.5-h mission routine that repeated through the course of the week. This mission routine required the lead pilot to give a briefing (typically close to an hour in duration) to the flight members concerning the upcoming mission. During the next hour, the four pilots then typically flew between four and eight air-to-air combat engagements of the same mission genre. An "engagement" or scenario is one setup where friendly and adversary forces were initialized at greater than 40 nautical miles and flew until the either the learning objectives were met or all friendly or adversary forces were eliminated. After completing the final mission's engagement, the pilots had 1.5 h in a debrief facility where each engagement was replayed, paused, or rewound for the pilots to discuss their performance. The debrief facility included a god's eye view and four multi-function displays from each cockpit. This cycle repeated each morning and afternoon until the pilots completed training research around midday on Friday (nine total missions). These missions followed a "building block" approach; that is, missions gradually became more complicated as the missions progressed (e.g. more threats were present).

In near real-time, Subject Matter Experts (SMEs) were asked to evaluate the team's performance, utilizing numerous computerized resources at their disposal. These included the god's eye view, all pertinent cockpit instrumentation for each pilot, various instructor-operator station functions (e.g. recorded shot information and alternative viewpoints), and all communication. This information was the basis for the SMEs to provide subjective evaluations used as our dependent measures. The SME raters used the following scale:

0: Performance indicates a lack of ability or knowledge.
1: Performance is safe, but indicates limited proficiency.
2: Performance is essentially correct. Recognizes and corrects errors.
3: Performance is correct, efficient, skillful and without hesitation
4: Performance reflects an unusually high degree of ability

3. Results

Our work in syllabus development for the US Air Force Fighter Weapons School has been extremely well received and has generated considerable data on the benefits and effectiveness of competency-based training. Participating pilots explicitly reported that this DMT learning environment benefited them by providing opportunities to lead multiple aircraft engagements, the opportunity to "see" multi-aircraft adversary presentations, the opportunity to fight against advanced adversary missiles, the benefit of an advanced digital debrief facility, and the overall gain they received for the time spent in the learning environment.

Results of a preliminary descriptive analysis of the SME ratings support these assertions. In Table 2, we report the mean mission scores given by the SME raters on the participating pilots' problem solving supporting competencies. The numbers show participant group mission means of SME ratings for the entire four-ship of F-16 pilots. These mission means—*unweighted* for the increases in mission complexity—show a generally flat to moderate increase in those problem solving supporting competencies. Furthermore, follow-up on the participants at the USAF weapons school by USAF weapons instructors revealed that there was a 6% reduction in non-effective training sorties and that the students showed a marked improvement in radar procedures, situational awareness, communications, and weapons employment.

4. Discussion

Environments such as DMT represent a major technological advance in the development and delivery of training and rehearsal for warfighting. Interconnecting multiple, real-time simulators together with computer-generated forces in a competency-driven and instructionally valid manner creates an environment that is unconstrained compared with normal training environments from the perspective of the trainee and at the same time highly controlled by instructors. A well-designed training exercise will serve to improve warfighter proficiency on specific tasks in order to meet specific objectives.

The high-fidelity networked simulation environment of DMT clearly has had its benefits for aiding air combat pilots in developing higher order problem solving supporting competencies defined by Air Superiority MECs. The self-reported pilot

Table 2
Results across mission intervals on problem solving-related objectives

		Mission								
		1	2	3	4	5	6	7	8	9
Engagement decision	*M*	2.17	2.17	2.58	2.41	2.46	2.27	2.70	2.58	2.76
	SD	0.76	1.18	0.40	0.43	0.33	0.49	0.43	0.40	0.50
	n	3	2	7	11	11	10	11	10	10
Tactical intercepts										
Targeting	*M*	2.58	2.42	2.59	2.51	2.64	2.34	2.54	2.40	2.57
	SD	0.72	0.82	0.53	0.50	0.39	0.65	0.77	0.58	0.75
	n	3	2	7	11	11	10	11	10	10
Sorting	*M*	2.28	2.17	2.34	2.38	2.34	2.35	2.41	2.47	2.54
	SD	0.75	1.18	0.49	0.49	0.44	0.48	0.80	0.48	0.62
	n	3	2	7	11	11	10	11	10	10
Intercept geometry	*M*	2.22	2.17	2.25	2.35	2.33	2.43	2.53	2.37	2.68
	SD	1.07	1.18	0.59	0.47	0.49	0.59	0.47	0.40	0.51
	n	3	2	7	11	11	10	11	10	10
BVR launch and leave	*M*	2.33	1.50	2.62	2.32	2.30	2.03	2.43	2.50	2.68
	SD	0.94	0.00	0.21	0.53	0.54	0.76	0.58	0.50	0.46
	n	2	1	4	11	11	10	11	10	10
BVR launch and react	*M*	2.44	1.33	2.44	2.19	2.36	2.16	2.42	2.21	2.69
	SD	0.96	0.00	0.41	0.59	0.54	0.61	0.83	0.67	0.36
	n	3	1	4	11	11	10	11	9	9
Radar operation procedures										
Utilizing correct mode	*M*	2.67	2.50	2.70	2.66	2.49	2.66	2.86	2.75	3.08
	SD	0.58	0.71	0.43	0.59	0.55	0.42	0.31	0.39	0.53
	n	3	2	7	11	11	10	11	10	10
Weapons employment	*M*	2.53	2.33	2.37	2.30	2.18	2.65	2.60	2.62	2.59
	SD	0.68	0.94	0.40	0.40	0.75	0.36	0.49	0.51	0.35
	n	3	2	7	11	11	10	11	10	10
Judgment	*M*	2.31	2.25	2.33	2.47	2.37	2.03	2.48	2.29	2.64
	SD	0.93	1.06	0.45	0.46	0.27	0.49	0.69	0.55	0.64
	n	3	2	7	11	11	10	11	10	10
Gameplan										
Adjusting plan on-the-fly	*M*	2.06	2.00	2.07	2.30	2.23	1.99	2.14	2.17	2.40
	SD	0.92	1.41	0.50	0.58	0.41	0.55	0.52	0.49	0.78
	n	3	2	7	11	11	10	11	10	10
Communication	*M*	2.17	1.50	2.07	2.39	2.40	2.22	2.58	2.42	2.61
	SD	1.04	0.71	0.57	0.66	0.55	0.50	0.58	0.65	0.59
	n	3	2	7	11	11	10	11	10	10

(*Table continued on next page*)

Table 2 (*continued*)

		Mission								
		1	2	3	4	5	6	7	8	9
Overall engagement grade	*M*	2.08	2.17	2.10	2.16	2.08	1.93	2.05	2.22	2.43
	SD	0.72	1.18	0.46	0.52	0.41	0.61	0.62	0.52	0.59
	n	3	2	7	11	11	10	11	10	10

Sample sizes for some cells are less than 11 due to the specific nature of that mission or objective. For example, missions one and two early in the week for many groups frequently required more fundamental engagements that prohibited the SME from rating that construct for the entire four-ship of F-16 pilots.

participant feedback, instructor pilot feedback, and data obtained from SME expert raters all provide evidence for this. The next phase of our research will elaborate on assessing these problem solving supporting competencies. Extensive effort is being undertaken to develop real-time computerized measurement techniques that capture and assess specific knowledge, skill, and supporting competency contexts. These new measures will allow deeper understanding into the precise knowledge and skill a pilot or team may lack when they exhibit difficulty problem solving an engagement. Since these measures will be real-time, an instructor can then use these computerized assessments to optimize scenario selection for the upcoming mission's training objectives.

References

Bennett, W., Jr., & Arthur, W., Jr. (1997). *Factors that influence the effectiveness of training in organizations: a review and meta-analysis* (Interim Technical Report, AL/HR-TR-1997–0026). TX: Brooks AFB.

Cannon-Bowers, J. A., & Bell, H. H. (1997). Training decision makers for complex environments: implications of the naturalistic decision making perspective. In C. E. Zsambok, & G. K. Klein (Eds.), *Naturalistic decision making* (pp. 99–110). Mahwah: Erlbaum.

Cannon-Bowers, J. A., Tannenbaum, S. I., Salas, E., & Volpe, C. E. (1995). Defining competencies and establishing team training requirements. In R. A. Guzzo, & E. Salas (Eds.), *Team effectiveness and decision-making in organizations* (pp. 333–380). San Francisco, CA: Jossey-Bass.

Carroll, L. A. (1999). Multimodal integrated team training. *Communications of the ACM*, *42*(9), 69–71.

Colegrove, C. M., & Alliger, G. M. (2002). *Mission essential competencies: defining combat mission requirements in a novel way*. Paper presented at the NATO SAS-038 Working Group Meeting, Brussels, Belgium.

Crane, P. (1999). Implementing Distributed Mission Training. *Communications of the ACM*, *42*(9), 91–94.

Crane, P., Robbins, R., & Bennett, W. Jr. (2000). Using distributed mission training to augment flight lead upgrade training. In *Proceedings of 20th Industry/Interservice Training Systems and Education Conference*. Orlando, FL.

O'Neil, H. F. Jr. (1999). Perspectives on computer-based performance assessment of problem solving: editor's introduction. *Computers in Human Behavior*, *15*, 255–268.