Front-End Analysis: Top-Down, Bottom-Up, or Both?

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ABSTRACT

When developing a training curriculum for a new military platform, training analysts and instructional systems designers can use two basic approaches for content analysis: One, a top-down functional analysis of missions and the tasks which support them; or, two, a bottom-up approach of identifying the knowledge and skills required based on the platform systems and tasks. Each approach has different uses and outcomes. Applying both methods, though, has its merits for developing a complete and effective curriculum design.

Since 2004, the training systems support team at Naval Air Systems Command (NAVAIR) and The Boeing Company has been performing front-end analysis for the new P-8A Poseidon, a multi-mission maritime aircraft. This effort began with a top-down functional analysis of all aircraft roles and identifying associated mission tasks. The approach was intended to produce a purely task-based curriculum for pilot and mission crews. However, during the process, the team also applied a bottom-up analysis of the curriculum design to verify adequate coverage of content. Similarly a top-down, bottom-up approach was also applied to the instructional strategies to ensure instructional fidelity.

This paper presents a brief overview of the completed front-end analysis process and discusses some of the many lessons learned about the strengths and limitations of a large scale front-end analysis. Also discussed are the roles of instructional strategies in effectively sequencing tasks during design.

ABOUT THE AUTHORS

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P-8A POSEIDON

In 2004, the Boeing Company was awarded the contract to build an aircraft that would replace the P-3C Orion. The new aircraft, the P-8A Poseidon, is a variant of the popular next-generation 737. The P-8A Poseidon (see Figure 1) is a long-range anti-submarine warfare, anti-surface warfare, intelligence, surveillance, and reconnaissance aircraft. Capabilities for this aircraft include patrol and reconnaissance of maritime and littoral areas.

Figure 1. U.S. Navy P-8A Poseidon (rendering)

As part of the contract award, a training system is being developed for the operators of the production aircraft. The training system, which includes the devices and curriculum for pilot and mission positions, will enable operators to quickly transition from the P-3C Orion without a gap in mission readiness. This quick transition creates some challenges for the instructional designers responsible for the front-end analysis phase. The challenges are centered on the fact that the operator machine interface has been under development during the training task analysis phase and so the task procedures are still being defined. What is needed to enable a more effective curriculum design is a blended approach that captures the task-based learning objectives specific to the platform as well as bottom-up aircraft systems approach. In short, the goal of the front-end analysis was to identify the information needed to create a comprehensive task-based syllabus/curriculum framework for all the Navy personnel operating the P-8A over the life of the aircraft.

To give the front-end analysis some form during the development phase, a top-down functional analysis was performed to identify the functions and tasks that the aircraft needs to perform in order to accomplish identified aircraft missions. Due to having eight aircraft positions and three ground positions to analyze, management of the resulting task list requires tools, processes, and standards to keep products of the task analysis consistent.

These tools and processes are invaluable as the pilot and mission system mature and the task analysis data undergo reevaluation and updates. This reevaluation is an on-going, bottom-up validation and refinement of those tasks required to keep the training direction concurrent with the evolving aircraft capabilities. This paper describes the methodologies and tools used in the analysis, as well as some lessons learned. It also looks at processes and instructional strategies that bring the analysis products into a coherent and executable curriculum.

TOP-DOWN FUNCTIONAL ANALYSIS

A top-down functional analysis (TDFA) was conducted early in the P-8A development program as a method to identify and accommodate human systems integration factors. The goal of the TDFA is to provide a means for specifying, acquiring, developing, operating, and managing training systems that directly achieve mission and job task performance requirements. Although many of the steps associated with TDFA align more directly with the systems engineering activities, the products of this process also yield valuable task data relevant to the construction of the P-8A Training System. This data provided a sequential order for aircraft functions.

These functions resulted in a preliminary task listing for the P-8A. The TDFA provides traceability between Navy Mission Essential Tasks (NMETs), P-8A missions, and P-8A tasks. The National Air and Space Warfare Model (NASM) was used as part of the structure of the underlying functional analysis. Using the NASM structure, the P-3C Orion missions were divided into phases of flight, which were further decomposed into system functions. System functions describe how the system will achieve performance requirements. System functions are, in turn, decomposed into human and system tasks, which describe the qualitative and quantitative workload of operators and maintainers. These functions were linked to missions, which were linked to the NMETs in order to provide traceability of the missions to the NMET list (see Figure 2).

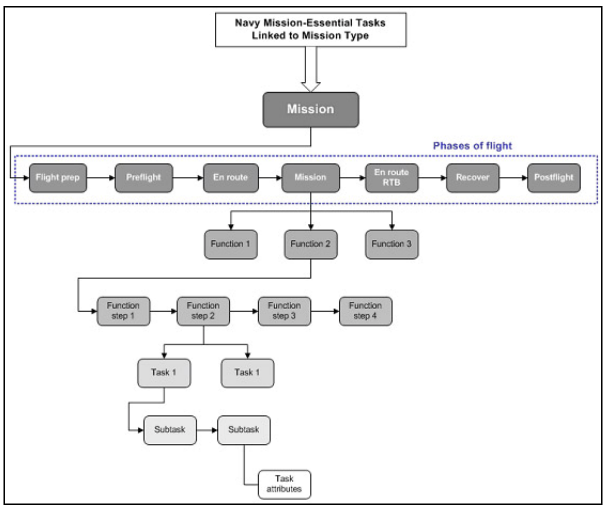

Figure 2. Relationship of P-8A Tasks to Navy Mission-Essential Task

This P-8A task list provides the basis upon which individual and collective tasks were developed. Individual tasks were defined as training performed by a single person within the aircraft. Collective tasks involve interactions with entities outside the aircraft. This function analysis was provided to the training system, designers who used it as a basis for its task analysis.

The Instructional Systems Design (ISD) team began the task analysis by identifying those P-3C functions and tasks that would continue to apply to the P-8A aircraft. Then the team identified tasks that were unique to the new platform. The team entered the tasks into a relational database tool, which is used on numerous company programs (see Figure 3). This tool was modified to accommodate the six mission crew positions (two acoustic operators, two non-acoustic operators, a Tactical Coordinator (TACCO), and a Co-TACCO), in addition to the pilot and copilot positions commonly found on other programs. The initial task list has continued to evolve as additional tasks are identified by the subject matter experts (SMEs) with whom the ISD team works.

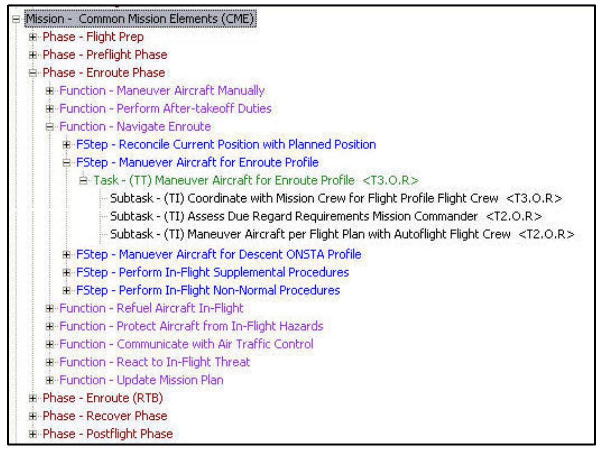

Figure 3. Top-Down Functional Analysis Tree for P-8A

The team continued its task analysis by isolating the crew position that performs each task and by rating the difficulty, importance, and frequency with which each tasks occurs. This data was used to determine those baseline tasks that require training. For those tasks requiring training, additional task attributes were collected in the database tool; including associated systems and subsystems, task cues and conditions, performance standards, supporting references and tools, and supporting knowledge and skills (see Figure 4).

The team is responsible for providing training for the crewmember's entire P-8A career, from the first time the crewmember enters the Fleet Replacement Squadron (FRS) until he or she leaves the community. The Navy uses an Air Combat Training Continuum (ACTC) program to provide the infrastructure necessary for its training. There are five levels of training on the continuum. ACTC 100 is defined by completion of FRS-level training; ACTC 200 is the intermediate training; ACTC 300 completion indicates that the aircrew member is fully qualified for his or her position, based on training and experience; ACTC 400 is for mission commander training and Wing training instructors; and ACTC 500 is training for individuals who will be functioning as Weapons Training Unit instructors.

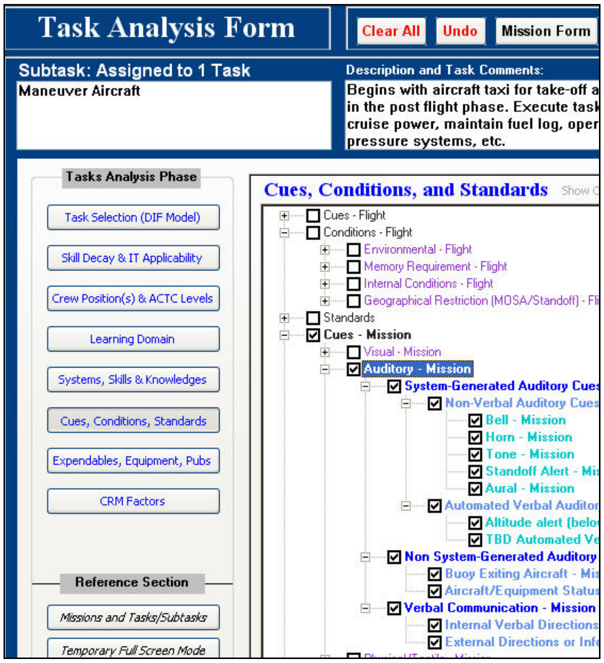

Figure 4. Systems Analysis

The task analysis results provided input to the learning analysis, during which the team developed task-based course objectives. Due to the large number of tasks for pilot and mission crew (approximately 2000), it was necessary to develop an algorithm for generating learning objectives for each position at different standard levels. Data from several front-end analysis activities were provided to the ISD team with the relevant information needed to populate fields in the objective statements. Because all of the analysis data had been captured in the relational database tool, the team was able to develop an automated process for constructing the learning objectives (see Figure 5).

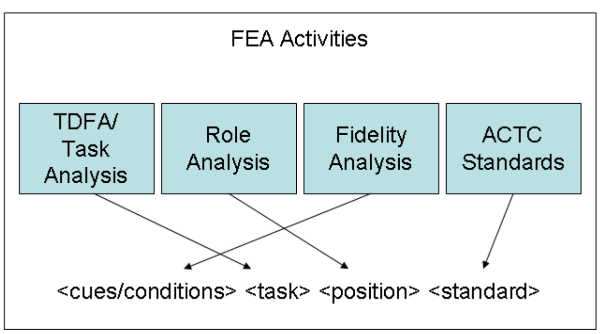

Figure 5. Automated Learning Objective Construction

The objectives serve two primary purposes for assessing student competency. They are either the basis for assessing a student's knowledge and skills or they serve to judge how well he or she will be able to successfully perform a particular task. Objectives developed using the P-8A task list were created from the top down due to the traceability through the task list to the NMET through the TDFA. Objectives developed for the supporting skills and knowledge, on the other hand, were created from the bottom up. For the curriculum designer, objectives are an integral part of the design process. They are the measures by which the tasks from the front-end analysis are translated into a description of what students will be able to do at the completion of their instruction. They serve as a guide for selecting and ordering instructional content and subsequently for performing media selection (Dick & Carey, 1990).

Following the learning analysis, the ISD team used the analysis to assign the learning objectives to tentative media in which to teach each task. The ISD team used the database tool to identify the most appropriate training delivery media based on attributes associated with each of the media under consideration. The algorithms the team used were based on the Academic/Hands-On Media (AHOM) selection model.

Media associations were based on how closely media attributes meet an instructional need. The model was applied to each learning objective, and attributes necessary to train each objective, such as type and immediacy of feedback, fidelity requirements, and motion requirements were identified and selected. The media selection model generates a list of appropriate training delivery media that supports the identified attributes. When multiple media could be used to train an objective with the same number of attributes, they were ordered based on cost.

The team's next step was to take all of the data and organize it into a coherent curriculum tied to the corresponding objectives and tasks. The curriculum design was a challenge for a number of reasons. When the team started its analysis, the hope was to automate as much of the curriculum design as possible.

The first obstacle the team met was that although all the data collected in the database tool lent itself well to a systems-based analysis, it did not easily facilitate the development of task-based curricula. The tool identified the tasks and objectives very well according to the system or systems used to perform the tasks. If the team were developing maintenance training, this would have fared well, but they are developing training for the P-8A flight and mission crew. The team needed to base its curriculum on tasks the aircrew needed to perform and the systems were not the task drivers.

Good instructional design calls for a top-down analysis. One starts with the highest level-tasks and breaks them down to the lowest levels, which usually ends with the "button-pushing" steps and the underlying skills and knowledge. However, on a new aircraft that is being developed concurrently with performing the task analysis, the team could not break down the tasks to their lowest level. In all cases, the specific procedures to accomplish tasks were not yet documented. Therefore, it was impossible to conduct a strictly top-down approach to the analysis, and thus the curriculum. Too much information was missing. The team discovered that it needed to consider how much information about the systems needed to be taught without knowing the specifics. The team knows what systems exist and what their functions are supposed to be, but it did not have all the specifics necessary to continue the analysis from the top down. The team also needed to consider the training from the bottom up.

Our customer provided direction that they did not want to train on any system below the level that the students could control. In other words, they did not want to train down to the schematic level unless knowing such detail allowed the student to work around or resolve a problem that occurs during the mission. If there is nothing the student can do about a problem with the system, then they do not need to be trained on the details of the system.

Given this direction and knowing the underlying aircraft systems that require training, the team was able to make certain assumptions about what needed to be trained, regardless of the system. The team could definitively state students would need to know panel locations and general system functionality. The team also knew that students would need to perform basic operating procedures on those systems, such as system configuration, startup, and shutdown. Again, due to the emergent state of the systems functionality, procedures for these functions could not be defined during the analysis phase. By approaching the task analysis from the bottom up on the systems aspects of the aircraft, the team was able to create a curriculum even with data that was in a state of flux.

Additionally, the team hoped to automate as much of the bottom-up analysis as possible by using software to automatically create objectives based on underlying skills and knowledge. The team tried to automate objective creation by using the database and the tasks that were identified in the top-down phase of the analysis. Then using the Bloom's (1956) taxonomy of cognitive domains, along with Simpson's (1972) taxonomy of psychomotor domains, the ISD team selected verbs that reflected each level of the domains and applied the verbs to the various systems and subsystems. For example, a level-1 knowledge learning objective became "Locate the navigation system"; a level-2 knowledge statement became "Explain how the navigation system functions"; a level-3 knowledge statement became "Perform/apply the operating procedures, limitations, and safety precautions for the navigation system"; etc. Similar statements were developed for Simpson's seven levels of psychomotor learning objectives. The team recognized that these objectives would have to be refined at a later time when the team learned more about the relationship between the tasks and the systems.

INSTRUCTIONAL STRATEGY

Following the task analysis, the team transitioned to curriculum design and organizing the task into a coherent learning plan. While the purpose of the front-end analysis was to identify tasks that the operator must be able to perform on a given mission, the front-end analysis does not explain how to teach these tasks and objectives. Therefore, instructional strategies, based on learning theories, were the vehicles for structuring tasks into logical and meaningful sequences.

Instructional strategies can be derived using a top-down or bottom-up approach as well. At a macro level, instructional strategies in and of themselves are a top-down approach. The designer identifies desired end states and establishes rules and goals needed to achieve these states. Using these rules, the designer arranges instructional objectives and content into a structure that meets the intent of the overall strategy.

However, at the micro level or at the level where tasks and knowledge are actually taught, a bottom-up approach is more useful because it takes into account relevant experience, tactical and technical skill levels of the training audience. Micro instructional strategies specify how content should be taught based on the nature of the content. For example, a standard procedure may be best taught using a description, demonstration, activity, and then assessment for the student. Whereas factual information that must be memorized, may be best taught using mnemonics or drill and practice exercises.

Top-down versus bottom-up approaches applied to the curriculum design are used for different purposes and outcomes. Top down is theory and rule driven. For the

P-8A, these rules resulted in a hierarchal structure to ensure coverage of all content items. A bottom-up approach structures content in terms of the systems and tasks the student must learn. It generally requires people who have "been there, done that" who have a strong understanding of how knowledge and skill are actually applied in the field. Consequently, strategies can be wide and varied and result in many different structures (see Figure 6).

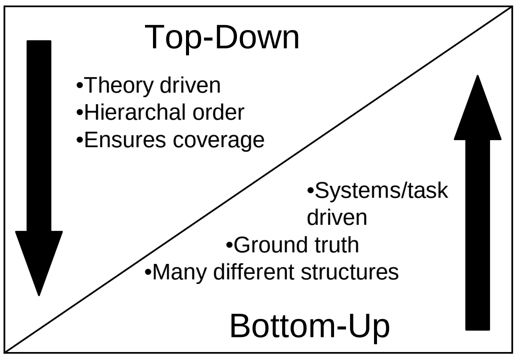

Figure 6. Top-Down, Bottom-Up Characteristics

Regardless of which method is used, the selection of an instructional strategy is based on several factors. Audience analysis, instructional media, learning setting, and customer direction are common variables in selecting the overarching approach to teaching students. For the P-8A, the designers spent a considerable amount of time identifying strategies that would expose learners to more skills and knowledge required to perform a mission. The goal of the training is to develop students who are integrated more quickly into an aircrew and are able to perform missions after leaving the schoolhouse. In line with this goal, the customer emphasized the need for task-based curriculum where students are actively involved in performing operations rather than the P-3C curriculum that focused heavily on systems understanding and an overall understanding of the aircraft. Additionally, the ISD team, along with the Navy customer, wanted the aircrews to have more experience working together and practicing critical crew resource management skills.

The fleet replacement squadron (FRS) is the first place students are exposed to aircraft-specific training. The FRS follows a traditional schoolhouse approach to help aircrew gain the basic knowledge and skills required for deployment. It is during this period of time for which the overarching instructional strategy needed to be created.

Based on the customer's goals and directions, the team established two main terminal objectives. First, learners completing the FRS need to be prepared to fly missions as an aircrew member (this included NATOPS and ACTC 100 level of qualification). Second, in order to be prepared to fly missions, students need to be familiar with their systems and tasks.

To accommodate these priorities, the ISD team adopted an overarching training philosophy that was based on two principles: a temporal approach to job performance and performance of basic skills and tasks increasing in complexity over time. For example, the first half of the training focuses on individual skill and knowledge development and the second half of the training emphasized missions, tactics and team coordination where students would execute what they actually learned in the individual training section. These concepts were used to create blocks of training showing the blended methodology (see Figure 7).

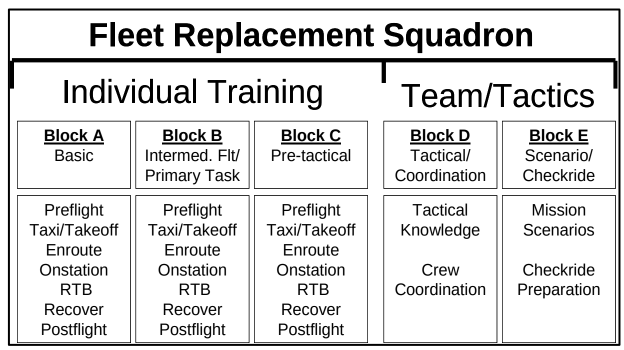

Figure 7. Block Approach to P-8A Training

Each block, in turn, had its own set of terminal learning objectives. Blocks were subdivided into units. Units were subdivided into lessons and finally into individual modules with groups of learning objectives based on similar tasks and media. This top-down approach to instructional strategies was necessary to ensure that effective and efficient coverage of all tasks and objectives were identified in the analysis phase.

Using the established rules, the team worked together to group learning objectives into their appropriate place in the curriculum. These rules, based on learning theories and instructional design best practices, provided a logical basis for when to teach tasks or objectives. In general, the parsing rules were as follows:

- Block:
    - Aircraft safety before mission-specific tasks

  - Simple to complex
  - Individual tasks before team coordination tasks
- Unit:
  - Chronological/temporal order (learn tasks in the same order you perform them)
  - Comparative sequence (known or familiar tasks first)
- Lesson/Event
  - Chronological/temporal order
  - Dependent/supportive tasks first
- Module
  - Supporting skills and knowledge
  - Grouped based on media type
  - Half hour to one-and-a-half hour time periods for classroom and computer-based training
  - Four hour device simulator events
  - Five hour flight events

This top-down rule base for the curriculum provided the framework for placing all task and objectives into logical positions. However, at the module level, the grouping was not as easy to order. A second pass at the curriculum was required from the bottom-up perspective. With regard to the systems being taught and prerequisite knowledge and skills, the team re-evaluated the grouping of individual objectives within modules.

While higher order rules may have placed related learning objectives together, the bottom-up perspective identified logic errors and areas that just were not feasible. The first curriculum development pass created a logical order based on top-down lesson rules. By revisiting the curriculum from the bottom up, the second pass allowed the team to create a much more coherent structure.

The top-down, bottom-up activities are essential to task analysis and curriculum design. The first provides an academic approach that focuses on theory and ensures that what needs to be taught gets taught. The second is a reality check from the hands-on perspective that looks at the sequence or grouping of items and whether or not an objective is actually necessary or sound. Looking at the curriculum from the top down, as well as the bottom up, proved to be invaluable. It is much like running a mathematical problem by first applying the theories and formulas to create an answer. Then, the problem is checked by looking at the answer and working it back to the problem to ensure it is correct and makes sense. With millions of dollars and the well-being of the warfighter at stake, it is worth the time and money required to do a thorough review.

CONCLUSION

Four years have passed since the front-end analysis work began on the P-8A. The efforts of the front-end analysis included device design and definition, supporting facility development, and overall training system concept (Weeks & Stafford, 2006). Now, as the curriculum design work is being finalized, the team is noting as a lesson learned that neither the top-down or bottom-up approach is sufficient for a comprehensive front-end analysis. Rather a blended approach based on job performance and fundamental skills and knowledge is necessary for a thorough curriculum design.

Over the next three years, the team will be involved in development and implementation of the curriculum. The team is tasked with continual updating of the task analysis as mission systems mature and the aircraft completes flight test. This on-going process will ensure the concurrency of the training system with the aircraft.

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