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EXPERIMENTS TO BE FLOWN IN AN EARTH ORBITING LABORATORY: THE U.S. EXPERIMENTS ON THE FIRST INTERNATIONAL MICROGRAVITY LABORATORY, FROM CONCEPT TO FLIGHT

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ABSTRACT

A space life sciences flight experiment requires careful long-term planning. A key role of the Space Life Sciences Payloads Office is to guide the orderly development of a proposed experiment originating in a ground-based laboratory to be flown in an Earth-orbiting laboratory. The first International Microgravity Laboratory, to be launched in 1991, provides an example of the experiment development requirements necessary to ensure a maximum science return. All life science experiments defined for spaceflight have gone through a rigorous and competitive evaluation process: a peer review for scientific quality, a program review for relevancy, and an engineering review for feasibility. Less than 10% of all proposals to do life science experiments in space are accepted for definition as candidates for flight. The candidate experiments have limited options for a flight assignment (e.g., spacelab, secondary payload, and international cooperative flights). The flight assignment is based primarily on the experiment weight, orbital requirements, services (i.e., power, cooling, etc.), and crew time requirements. To maintain the science fidelity of the experiment, an experiment requirements document (ERD) is prepared by NASA in conjunction with the Principal Investigator (PI). This ERD is then used, again in conjunction with NASA and the PI, to define the hardware requirements and generate a hardware requirements document. A phased set of reviews (e.g., preliminary requirements review, preliminary design review) is held, culminating in a critical design review of the experiment when the hardware and experimental design is approximately 90% complete. The compatibility of the science with the hardware is then further evaluated with a biocompatibility test. The final science evaluation is the Experiment Verification Test, in which flight hardware is used to perform the experiment in a simulation of the flight. All the approximately 60 steps involved in placing a life science experiment in space are coordinate with the PI by a NASA research scientist, the Payload Scientist.

ACRONYMS

AO	Announcement of Opportunity
ARC	Ames Research Center
CDR	Critical Design Review
DPM	Deputy (FPI) Payload Manager
DPS	Deputy (FPI) Payload Scientist
ERD	Experiment Requirements Document
ESS	Experiment Support Scientist
EUE	Experiment Unique Equipment
EUH	Experiment Unique Hardware
EVT	Experiment Verification Test
FPI	Flight Payload Integration
IERD	Integrated Experiment Requirements Document
IRR	Integration Readiness Review
IML-1	First International Microgravity Laboratory
KSC	Kennedy Space Center
LSLE	Life Sciences Laboratory Equipment
MST	Mission Sequence Test
NASA	National Aeronautics and Space Administration
NRA	NASA Research Announcement
PDR	Preliminary Design Review
PI	Principal Investigator
PM	Payload Manager
PMM	Payload Mission Manager
POCC	Payload Operations Control Center
PS	Payload Scientist
PRR	Preliminary Requirements Review
QA	Quality Assurance
SLSPO	Space Life Sciences Payloads Office
STS	Space Transportation System
TMA	Test Monitoring Area

INTRODUCTION

This report presents the current life cycle of NASA Ames Research Center (ARC)–managed flight experiments. The report has two main purposes: The first is to bring to the attention of biologists, and in particular cell and plant biologists, some of the requirements for flying a life science experiment in space. The second is to introduce the subject to biologists embarking on studies in the field and to delineate some of the specific requirements that will be encountered by an ARC-managed microgravity experiment. This report is not intended to be an exhaustive encyclopedia of all techniques used to prepare an experiment to evaluate the effect of microgravity on plant and animal cells. However, many of the requirements are the same for all biological systems and for other NASA centers. A detailed presentation can be found in *Principal Investigator Handbook,* ARC Rev. 12/16/90.

This document emphasizes the Principal Investigator's (PI) involvement in the activities required for successful completion of major reviews. The PI support required for activities other than these reviews is also discussed, as are the interactions between ARC and the PI that will be required as problems or questions arise throughout experiment and payload development. It is impossible to predict the extent of this activity because it varies according to the complexity of the experiment and the flight experience of the PI.

THE NEED FOR MICROGRAVITY RESEARCH

Microgravity research is a high priority for most environmental biologists because the Earth's gravitational pull is an ubiquitous environmental factor. All organisms spend their entire existence experiencing an acceleration of 9.8 m/s^2. This force acts not only on entire organisms and their organs, but also on the free-moving and sedimentable structures within their cells. Every movement and action involves a reaction against gravity. To remain erect requires an expenditure of energy, in the form of either muscular activity or energy-intensive building of stiff members (bones and wood chitin are good examples). To move requires orientation and an expenditure of energy against gravitational force. All organisms developed in this constant field over eons, and their entire structure and function are probably strongly influenced by adaptation to this force.

The absence of this force, as in spaceflight, causes environmental biologists to ask questions. What must the release of gravity mean to the functioning of the organism? What will be the reactions of organisms when movement is free; when up and down are gone; and when weight, sedimentation, and convection disappear and the energy used in reacting against them can be put to other uses? What kinds of intra- and intercellular and organ reorientation (e.g., molecular, physiological, and morphological) will take place in a gravity-free environment? It is to questions like these that biologists are able to turn their minds now that manned and unmanned earth-orbiting research facilities have become available. To meet NASA's life sciences goals, questions like these must be answered, in part to gain greater understanding of basic biological processes, and in part to aid in the realization of permanent manned orbiting facilities and interplanetary spaceflight.

BACKGROUND

Since the early 1960s biological experiments have formed a small but significant proportion of the payloads on orbiting space vehicles, and a wide variety of plants, animals, microorganisms, and cell and tissue cultures have been carried. In 1962 the Soviet Satellite 2 carried, for example, mice, guinea pigs, and human and rabbit skin. In 1967 Biosatellite II was launched by NASA with 13 selected general biology and radiation experiments (e.g., amoeba, *Tradescantia, Neurospora,* wheat, bell pepper, and frog eggs). Since that time, experiments on numerous Soviet and U.S. flights have added to our knowledge and peaked our interest in understanding the microgravity phenomenon. This knowledge, together with knowledge gained from ground-based research, is continually used in NASA's Space Life Sciences research planning process (Figure 1).

EXPERIMENT LIFE CYCLE

Experiments start with an initial Proposal Evaluation and progress through Experiment Definition, Experiment Development, Flight Hardware Development, Payload Integration, and Flight phases. The flow of these activities is shown in Figure 2. Unlike most ground-based biological research, space-biology experiments have lead times of years, rather than days or weeks (see Figure 3). The complexity of the development process and of the skills needed requires that an experiment team be established.

The Experiment Team

In space research, the individual researcher becomes part of a large organizational network (hundreds to thousands of people, depending on the mission), with all that it entails in terms of project management, difficulties with information flow, restricted freedom of action, and restricted flight opportunities. This report stresses that a team approach is needed to ensure a successful microgravity experiment. The goal of this team (which may, for example, consist of the PIs, ARC, and the Payload Mission Manager [PMM]) is to maximize the scientific return while minimizing the time, effort, and funds required to define, develop, and implement the experiment for space. Consequently, this team will represent the experiment to science, engineering, and operations personnel at ARC, and to NASA Headquarters, the Mission Management organization, and other center organizations involved in the flight opportunity.

Proposal Evaluation

Experiment proposals for U.S. spaceflights come from many sources. In life sciences, there are four principal sources of investigations: proposals submitted in response to a NASA Announcement of Opportunity (AO) or NASA Research Announcement (NRA), unsolicited proposals, agreements of various types made by NASA, and studies prepared in response to NASA's critical medical or technological needs. To be defined for spaceflight, all life science experiments must go through a rigorous, competitive evaluation process that includes an external peer review for scientific quality, a program review for relevancy, and an engineering and cost review for feasibility.

Experiment Definition

Less than 10% of all proposals to do life science experiments in space are accepted for definition as candidates for flight. The preliminary experiment selection is based on the scientific merit of proposals and an initial assessment of feasibility, as indicated above. The accepted experiments are then further defined and their feasibility for spaceflight carefully evaluated against options for a flight assignment (e.g., dedicated Spacelab, secondary payload, and international cooperative flights); this is the Experiment Definition phase.

During Experiment Definition, the PI works with a member of the Payload Scientist's team. The Payload Scientist (a NASA research scientist) coordinates, with the PI, all the approximately 60 steps involved in placing a life science experiment in space; the team member involved in Experiment Definition is the Experiment Support Scientist (ESS). In this phase, the ESS works with the PI to define the experiment; this becomes an iterative process between the developing center (in this case, ARC) and the PI. The PI and the ESS establish an in-depth understanding of the experiment, which leads to the refinement of science objectives and approaches within the confines of the Space Transportation System (STS), and the evolution of resource requirements.

The Experiment Definition phase results in (1) an agreement about possible approaches to performing the experiment in space, and (2) a preliminary agreement about experiment requirements, including the number of specimens, the need for existing Life Sciences Laboratory Equipment (LSLE) (e.g., animal holding units, refrigerator, freezer, centrifuge), and the need for Experiment Unique Equipment (EUE) (unique flight equipment to be built for a specific experiment). The second agreement results in a list of tentative Spacelab resource requirements, such as experiment weight, power, and cooling, and crew time requirements. Because the Shuttle is a shared system, users are in competition with one another and with other Orbiter operations for all available resources, from mass capacity to crew time. Although a substantial level of resources is available to meet essential needs, the PI is encouraged to distinguish between requirements and desires and to use prudence in establishing the resource requirements of his/her experiment.

The Experiment Definition phase concludes with an Experiment Requirements Document (ERD) and an experiment Preliminary Requirements Review (PRR). A pool of defined candidate experiments is then formally selected by NASA Headquarters; from this pool, experiments are selected for development.

Experiment Development

During Experiment Definition or at PRR, supporting studies necessary for the development and implementation of the experiment are agreed upon by NASA and the PI. Supporting studies are generally used to demonstrate the efficacy of an approach or hardware in performing the experiment. These studies are initiated by the PI during Experiment Development (Figure 3), and they influence the design of the experiment and of Experiment Unique Hardware (EUH).

Further refinement of the experiment requirements continues until the experiment Preliminary Design Review (PDR), at which time the full ERD is baselined (no further changes will be made without a formal review). Initial design approaches are presented at this PDR and project concurrence/direction is obtained to continue design approaches or initiate new approaches. When the design is 90% or more complete, the experiment Critical Design Review (CDR) is held, at which changes ("deltas") in science requirements are presented and the experimental design is baselined.

Flight Hardware Development

During the Experiment Development effort, prototype hardware is developed and tested for function, support of science objectives, and biocompatibility; this leads to a full experiment test and an SLSPO acceptance review. Upon acceptance, an experiment is ready for incorporation into a payload and for development of flight hardware. Under certain circumstances, an experiment may be assigned to a payload prior to experiment acceptance. Regardless of path, flight hardware is developed in the same manner as the experiment—in stages, with a similar review cycle (PRR, PDR, CDR, acceptance).

Payload Integration

The payload development approach at ARC comprises four areas of activity: payload selection, hardware/data system development, payload development, and payload integration. Mission development at the Mission Management Center proceeds along a similar path with a similar set of reviews. There is a sequential flow of activities in each area. Activities in some areas may depend on the completion of activities in another area. For example, the experiment CDRs in the experiment development stage must precede the payload PDR in the payload development stage, which in turn must generally precede the mission PRR (see Figure 3).

To define the payload experiment requirements, resource, interface, and feasibility information that was gathered during the experiment definition and development processes is combined with information provided by the PIs and the ESSs for other experiments. This results in an Integrated Experiment Requirements Document (IERD). The series of reviews for payloads and missions reflect the developing nature of the experiments, and the experiments become more refined as the cycle progresses. Included in each review are a description of the experiment science, a list of experiment requirements, a Safety Compliance Document, and schedules.

Once the payload is selected and developed, the Experiment Verification Test (EVT) is conducted. This is a final science evaluation in which flight hardware is used to perform the experiment in a simulation of the flight. Upon completion of this test, the experiments and payload are approved by NASA

Headquarters, and the payload is integrated into the Spacelab and Shuttle in preparation for flight.

Flight

This activity includes the preparation of flight specimens, the loading of the specimens into the flight hardware, and the loading of the hardware into the Shuttle. After launch, the flight is monitored at the Flight Support Facility at Kennedy Space Center (KSC) (where ground controls may be run simultaneously with the flight experiment) and the Payload Operations Control Center (POCC) by the PI and the Experiment Team. Recovery of specimens after flight may be at KSC or at Dryden Flight Research Facility (depending on the constraints of the Mission) by other members of the Experiment Team. The specimens are then given to the PI for post-flight processing, which culminates in a PI final report. The results of this experiment are then used to further refine NASA's program objectives, thus completing the cycle (Figure 1).

Example

The first International Microgravity Laboratory (IML-1), to be launched in January 1992, provides an example of the experiment development requirements necessary to ensure a maximum science return. The Space Life Sciences Payloads Office (SLSPO) at ARC developed five experiments that will fly on IML-1. Two of the experiments are Dr. Allan H. Brown's "Gravitropic Response of Plants in the Absence of a Complicating g-Force" (GTHRES) and Dr. David G. Heathcote's "Post Illumination Onset of Nutation at Zero G" (FOTRAN). Both experiments will fly in the Gravitational Plant Physiology Facility, a suite of hardware that fits into a Spacelab double rack.

The other three experiments supported by SLSPO will be flown in the European Space Agency's Biorack facility. The experiments are Dr. Gregory A. Nelson's "Genetic and Molecular Dosimetry of HZE Radiation" (US-1), Dr. Carlo V. Bruschi's "Microgravitational Effects on Chromosome Behavior of Yeast" (US-2), and Dr. Pauline Jackie Duke's "Chondrogenesis in Micromass Cultures of Mouse Limb-Bud Mesenchyme Exposed to Microgravity" (US-3). Hardware was developed for all three experiments to fit into the European Space Agency's "Type I/O" or "Type II/O" containers.

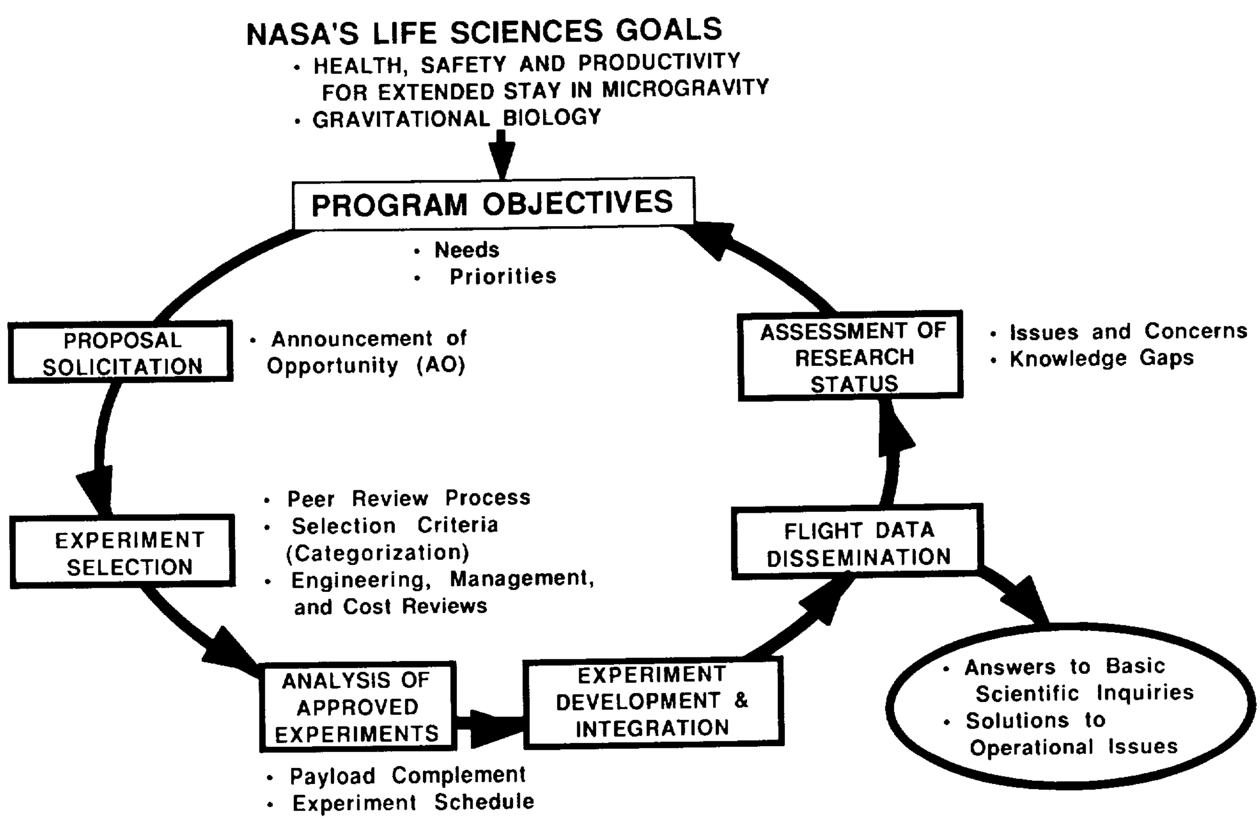

Figure 1. Space Life Sciences research planning process.

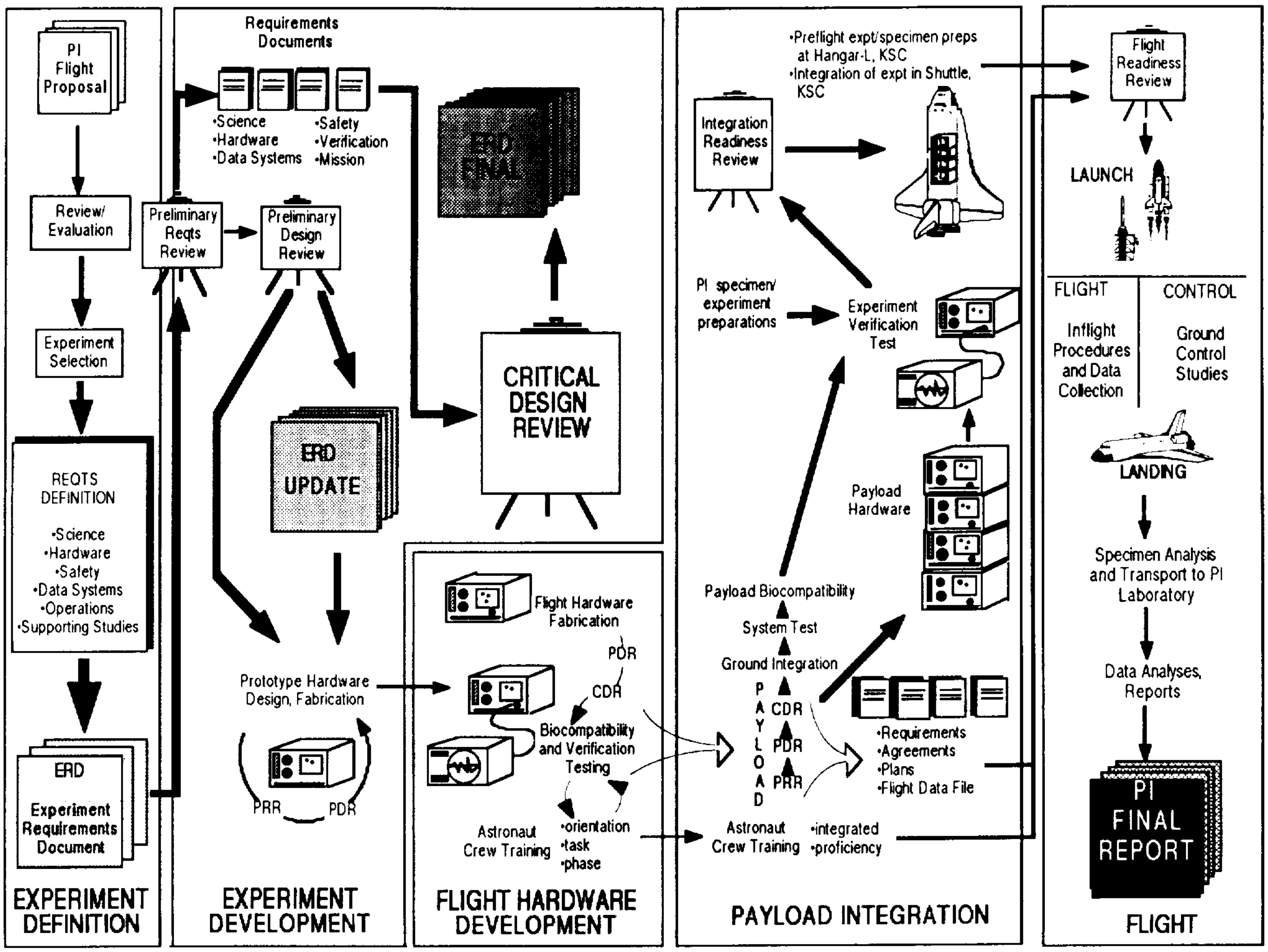

Figure 2. Phases of an experiment, from Proposal to Flight.

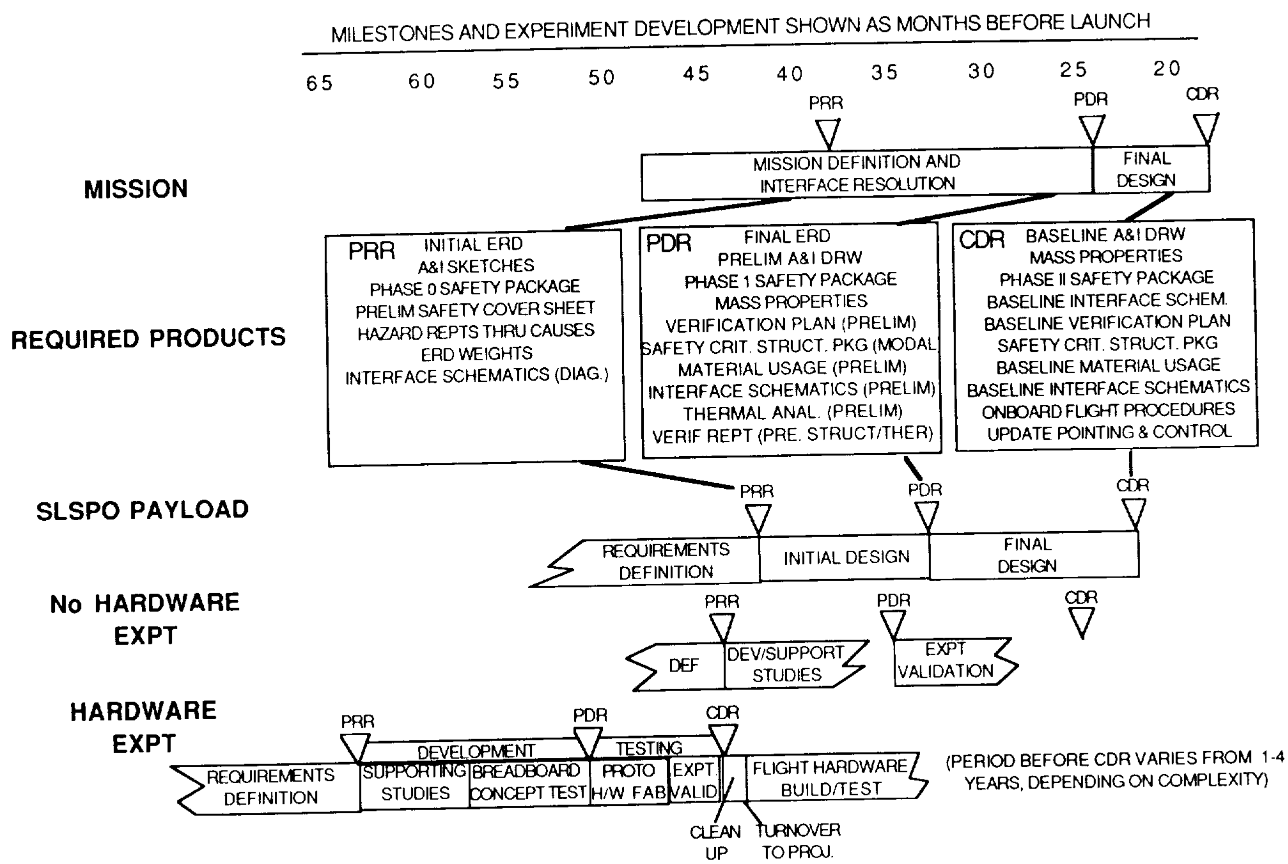

Figure 3. Timelines for an experiment's development.