Data, Information, and Knowledge

1. Understanding the Differences

To fully grasp the nature of **knowledge**, it is essential to distinguish it from **data** and **information**.

- **Data** consists of **discrete, objective facts** about events.
  - Example: Experimental observations from product testing or sales figures from a marketing study.
- **Information** is **processed data** that conveys a meaningful message.
  - Example: Sales data analyzed to identify **potential markets** or product test results compared to competitors.
- **Knowledge** is **broader, deeper, and richer** than both data and information.
  - It is a blend of **experience, values, contextual understanding, and expert insight** that helps in decision-making.

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2. Transformation of Data into Information

Data becomes **information** when **meaning** is added to it. This transformation occurs through:

- **Contextualization:** Understanding the **purpose** of data collection.
- **Categorization:** Identifying **key components** or units of analysis.
- **Calculation:** Applying **mathematical or statistical** analysis.
- **Correction:** Removing **errors** from the data.
- **Condensation:** Summarizing data for clarity and conciseness.

Example: Raw sales numbers are **data**; sales trends analyzed to identify consumer behavior patterns become **information**.

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3. Transformation of Information into Knowledge

Unlike data and information, **knowledge requires judgment** and critical thinking. This transformation occurs through:

- **Comparison:** Relating new information to **previous experiences**.

- **Consequence:** Understanding the **implications** for decision-making.
- **Connections:** Linking knowledge to **other related concepts**.
- **Conversation:** Discussing and **validating** ideas with others.

Example: An article on **bearing failure life calculations** in an engineering journal is **knowledge**, as it integrates **expert analysis, application, and implications**.

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4. The Role of Heuristics in Knowledge Application

Knowledge is often applied using **heuristics**—also known as **rules of thumb**. These are:

- **Experience-based guidelines** that provide quick solutions to complex problems.
- Frequently used in areas like **design for manufacturing (DFM)**.

Example:

- A **component specification** or **material data sheet** is **data**.
- A **catalog listing bearing dimensions and performance** is **information**.
- An **engineering journal article on bearing failure life** is **knowledge**.

Information Literacy and the Internet

1. The Internet as a Primary Information Source

The Internet has become the most common starting point for information searches. It functions as a **global network** of computers that transmit data, similar to how highways facilitate transportation. Just as the **Federal Aid Highway Act of 1956** revolutionized travel in the U.S., the Internet enabled the **World Wide Web (Web)**, transforming information access worldwide.

The **Web** is a vast collection of information accessible through the Internet. It has allowed traditional brick-and-mortar businesses to establish an **online presence**, enabling e-commerce, online banking, and digital government services. Many **non-commercial organizations**, such as charities and professional societies, also use the Web to share information.

2. The Shift in Information Accessibility

Before the Internet, information credibility was tied to the **type of source** (e.g., newspapers, academic journals, government reports). However, the Web now delivers an **overwhelming volume of information**, often unfiltered, making **credibility assessment** crucial.

Unlike traditional media, **Web-based information may be:**

- **Unverified** (lacking peer review or editorial oversight).
- **Anonymous** (authorship may not be clear).
- **Biased** (influenced by commercial or political interests).
- **Unstable** (subject to change or removal over time).

This necessitates a **new literacy skill**—the ability to **evaluate online information for credibility and quality**.

3. The Importance of Information Literacy

Since the 1940s, educators have developed methods for **identifying, sourcing, and evaluating** information. These skills are collectively known as **information literacy**—the ability to find, assess, and use credible information effectively.

Organizations such as the **Association of College & Research Libraries (ACRL)** provide guidelines for evaluating Web-based information. Resources like the **Purdue Online Writing Lab (OWL)** compare traditional and online sources, helping researchers develop critical evaluation skills.

4. Evaluating Online Information Sources

To determine the **credibility and reliability** of Web-based information, researchers should consider:

A. Standard Reference Materials (Digital & Print)

- Many **university libraries** provide online portals for academic journals, books, and reports.
- These digital sources often have **print equivalents**, making them more reliable.
- Such materials should still be evaluated based on authorship and publication credibility.

B. Web-Only Publications

- Information **published exclusively on the Web** must be evaluated rigorously.
- Anyone can publish online, so information should be **unbiased, accurate, and corroborated by other sources**.

5. Steps for Evaluating a Web Page

1. Review Website Design and Style

- Does the page **meet modern Web publishing standards**?

- Is the website cluttered with **advertisements**?

2. Check for Bibliographic Information

- Look for a **proper citation format**:
  Author Name, "Article Title," Organization, Date of Publication, Web, Access Date.
- If citation details are missing, it may indicate **low credibility**.

3. Identify the Author or Publisher

- Does the page list an **author**? If so, check their **credentials and previous publications**.
- If no author is listed, look for the **sponsoring organization**:
  - What is its **reputation**?
  - Could the content be **biased** toward the organization's interests?

4. Look for a Publishing or Update Date

- When was the content **originally uploaded**?
- Has the page been **updated** recently?
- Is the information **time-sensitive**?

5. Read and Analyze the Content

- Is the **writing professional** and free of **spelling/grammar errors**?
- Does the content **align logically** with the title and search intent?
- Are there **contradictions or gaps** in the reasoning?
- Are **external links active** and appropriately **cited**?

Finding Sources of Design Information

1. The Variety of Design Information

Design information exists in multiple formats, including:

- **Physical form** (existing designs and prototypes).
- **Print form** (historical sales data, manuals, textbooks).
- **Digital format** (company databases, proprietary files).

Companies maintain **proprietary design data**, while engineers rely on **technical sources** such as textbooks, journals, and monographs. Identifying and acquiring the right information is critical for a **successful design project**.

2. The Challenge of Finding Design Information

- Engineers spend **up to 30% of their time** searching for information.
- The **Internet has revolutionized access**, making public design data widely available.
- Designers must develop **efficient search strategies** to find relevant data.

3. Types of Design Information

Design projects require diverse information, including:

- **Marketing data** (customer needs, sales trends).
- **Existing product details** (benchmarking competitors).
- **Engineering calculations** (performance metrics, tolerances).
- **Material properties** (strength, durability, cost).
- **Manufacturing processes** (efficiencies, feasibility).
- **End-of-life disposal options** (recycling, environmental impact).

4. Sources of Design Information

Because design information is so diverse, engineers must refer to **multiple sources** rather than relying on a single document. Table 4.2 (referenced in the notes) likely categorizes sources based on their **reliability and accessibility**, such as:

- **Academic Sources** (textbooks, peer-reviewed journals).
- **Industry Reports** (market research, manufacturing guidelines).
- **Government Databases** (safety regulations, patents).
- **Company Data** (internal design documents, proprietary research).
- **Online Repositories** (technical standards, open-source engineering resources)

TABLE 4.2
Sources of Information Pertinent to Engineering Design

Libraries
- Dictionaries and encyclopedias
- Engineering handbooks
- Texts and monographs
- Periodicals (technical journals and magazines, and newspapers)

Government
- Technical reports
- Databases
- Search engines
- Laws and regulations

Engineering professional societies and trade associations
- Technical journals and news magazines
- Technical conference proceedings
- Codes and standards, in some cases

Intellectual property
- Patents, both national and international
- Copyrights
- Trademarks

Personal activities
- Buildup of knowledge through work experience and study
- Contacts with colleagues
- Personal network of professionals
- Contacts with suppliers and vendors
- Contacts with consultants
- Attendance at conferences, trade shows, exhibitions
- Visits to other companies

Customers
- Direct involvement
- Surveys
- Feedback from warranty payments and returned products

“Google It” – Searching for Information

1. The Meaning of "Google It"

The phrase *“Google it”* refers to using the **Internet**—specifically Google—to search for information. Given that there were **1.89 billion websites** as of July 2018, search engines are essential for finding relevant content efficiently.

2. Search Engine Market Share

From July 2017 to July 2018, the most widely used search engines were:

- **Google** – 72.2% market share (dominant player).
- **Baidu** – 3.7% (popular in China).
- **Bing** – 7.7% (Microsoft’s search engine).
- **Yahoo!** – 4.6% (once a major competitor).

Google remains the most popular search engine worldwide, making it the focus of most search-related discussions.

3. How Google Search Works

When users enter **keywords** in the search field, Google:

1. **Analyzes** the keywords and their context.
2. **Retrieves** a ranked list of relevant web pages.
3. **Displays results** based on complex ranking criteria.

Google does **not search the entire Internet in real time**. Instead, it uses:

- **Web Crawlers** – Automated programs that scan and index web pages.
- **Search Index** – A massive database of web content, which is referenced when users perform searches.

4. Google’s Search Ranking System

Google ranks search results based on several factors, including:

- **Keyword Presence** – The relevance of the search terms on the webpage.
- **Number of Links** – How many websites link to (or from) the page.
- **User Location** – Results may be personalized based on geography.

- **Page Load Speed** – Faster-loading pages rank higher.
- **Content Freshness** – Recently updated content is often prioritized.

These **ranking algorithms** constantly evolve, affecting how search results are displayed.

5. Importance of Search Rankings

The position of a webpage in Google's **search results list** directly affects:

- **Visibility** – Higher-ranked pages get more clicks.
- **Website Traffic** – Businesses depend on top rankings for online success.

6. Search Engine Optimization (SEO)

Many businesses hire **SEO specialists** to:

- Improve webpage **ranking** in search results.
- Optimize **content** and **keywords** to attract visitors.
- Enhance **user experience** and **website performance**

Example 4.1: Searching for Technical Information on Proportional Control

1. Initial Search – Broad Results

- **Search Query:** proportional control
- **Results:** 126,000,000 web pages.
- Google provides a **featured snippet** from Wikipedia and a list of related searches (e.g., "proportional controller basics").
- The large number of results indicates that Google finds the words **proportional** and **control** separately in many pages, not necessarily as a phrase.

2. Refining the Search – Exact Phrase Matching

- **Search Query:** "proportional control" (using quotation marks).
- **Results:** 439,000 web pages.
- This narrows results to pages where **proportional control** appears as an exact phrase.

3. Excluding Irrelevant Results

- **Search Query:** "proportional control" -temperature

- **Results:** 273,000 web pages.
- The **minus (-) sign** before a word **excludes** it from results, filtering out pages related to **temperature control**.

4. Expanding the Search – Using OR Operator

- **Search Query:** proportional OR control
- **Results:** 3,110,000,000 web pages.
- The **OR operator** broadens the search by including results containing either **proportional** or **control**, leading to an extremely large number of results.

5. Importance of Search Refinement

- **Efficient searching** requires **narrowing down** results for relevance.
- **Google's search tools** (quotation marks, minus sign, OR operator) help refine searches effectively.
- **Support for Google Search** is available at support.google.com.
- Searching *"How to search with Google"* can yield over **6 trillion results**, highlighting the vastness of web-based information.

Using **informed search techniques** allows engineers and researchers to quickly find **precise, relevant** information.

Library Sources for Design Information

1. Encyclopedias

- **Wikipedia** is a widely used online encyclopedia.
- It provides a **quick overview** of technical topics but may contain **errors or biases**, especially in political or economic discussions.

2. Handbooks

- Handbooks compile **technical information and data** by experts.
- They often include **theory, principles, applications, and detailed data**.
- Many handbooks are available in **library reference sections** or online by **subscription**.
- **Examples of handbook topics**:
    - Engineering fundamentals

- Mechanical engineering calculations
- Stress and strain formulas
- Fatigue testing
- Bolts and bolted joints

3. Textbooks and Monographs

- **Textbooks**: Often serve as **primary reference sources** for technical topics.
- **Monographs**: More **specialized books** focusing on **specific topics**.

4. Catalogs, Brochures, and Manuals

- Provide **information on materials, components, and products** from suppliers.
- **Trade shows** offer a great way to explore new products.
- **Thomas Register of American Manufacturers** (www.thomasnet.com) is a major resource for **finding industrial suppliers**.

5. Statistical and Business Information

- Government databases collect **sales and consumption data**.
- Available through:
  - **U.S. Department of Commerce's Census of Manufacturers**
  - **Bureau of the Census Statistical Abstract of the United States**
- Data are categorized by the **North American Industry Classification System (NAICS)**, which **replaced the SIC code**.

6. Periodicals (Technical Journals & Trade Magazines)

- **Technical Journals**: Publish **research results** in fields like **engineering design** and **applied mechanics**.
- **Trade Magazines**: Focus on **current industry practices** rather than research.
- **Abstracting & Indexing Services** help retrieve periodical literature.
  - These services also index **books, conference proceedings, reports, and patents**.
  - Accessible digitally through **library portals**.
- **Common abstract databases**:

  - **Web of Science**
  - **Google Scholar Citations** (shows articles that reference a source).
- **Citation count** helps gauge the **impact and value** of an article.

TABLE 4.3 Common Databases for Access to Engineering Abstracts and Indexes

Name	Description
Academic Search Premier	Abstracts and indexing for over 7000 journals. Many full text.
Aerospace Database	Indexes journals, conferences, reports by American Institute of Aeronautics and Astronautics (AIAA), Institute of Electrical and Electronics Engineers (IEEE), American Society of Mechanical Engineers (ASME).
Applied Science & Technology	Includes buyers guides, conference proceedings. Most applied of group.
ASCE Database	All American Society of Civil Engineers documents.
Compendex	Electronic replacement for Engineering Index.
Engineered Materials	Covers polymers, ceramics, composites.
General Science Abstracts	Coverage of 265 leading journals in United States and United Kingdom.
INSPEC	Covers 4000 journals in physics, electrical engineering, computing, information technology.
IEEExplorer	Electrical engineering and electronics.
Mechanical Engineering	Covers 730 journals and magazines.
METADEX	Covers metallurgy and materials science.
Safety Science and Risk	Abstracts from 1579 periodicals.
Web of Science	Covers 5700 journals in 164 science and technology disciplines.
Science Direct	Coverage of 1800 journals; full text for 800.

Google Scholar: A Tool for Scholarly Research

1. Overview of Google Scholar

- **Google Scholar** (scholar.google.com) is a **specialized search engine** for academic and scholarly literature.
- It searches sources like:
  - **University publications**
  - **Professional societies**
  - **Academic publishers**

  - **Court opinions** (if selected)
  - **Patents**
  - **Other academic websites**
- Unlike general Google searches, results are **ordered by relevance**, based on:
  - **Author prominence**
  - **Publication reputation**
  - **Recency and citation count**

2. Searching on Google Scholar

- Searches can be conducted using:
  - **Author name**
  - **Topic keywords**
  - **Date range**
  - **Other bibliographic details**
- **Advanced search techniques** (similar to Google) can refine search results.

3. Features of Google Scholar

- **Full-Text Access**: Provides links to full-text articles if available.
- **Citation Generator**: Offers citations in various formats (APA, MLA, etc.).
- **Citation Tracking**: Shows all publications citing a given article.

4. Example Search: Proportional Control

Step 1: General Search

- **Search term**: proportional control
- **Results**: ~3,630,000
- **Top result**: A 1963 article on **temperature regulation in human biology** (not engineering-related).

Step 2: Refining by Field

- **Search term**: proportional control AND engineering

- **Results**: ~1,890,000
- **Top result**: 2009 article on **active disturbance rejection control** (IEEE Transactions).

Step 3: Filtering by Date

- **Filter applied**: "Since 2018"
- **Results**: ~21,300
- **Top result**: 2018 book on **intelligent control and fuzzy logic**.

EMBODIMENT DESIGN

Introduction to Embodiment Design

1. Transition from Concept to Detailed Design

- Previous chapters covered **engineering design processes** up to **concept generation and evaluation**.
- Now, **selected concepts** are further developed with defined **dimensions, components, and materials**.
- This phase is known as **embodiment design**—where the concept takes **physical form**.

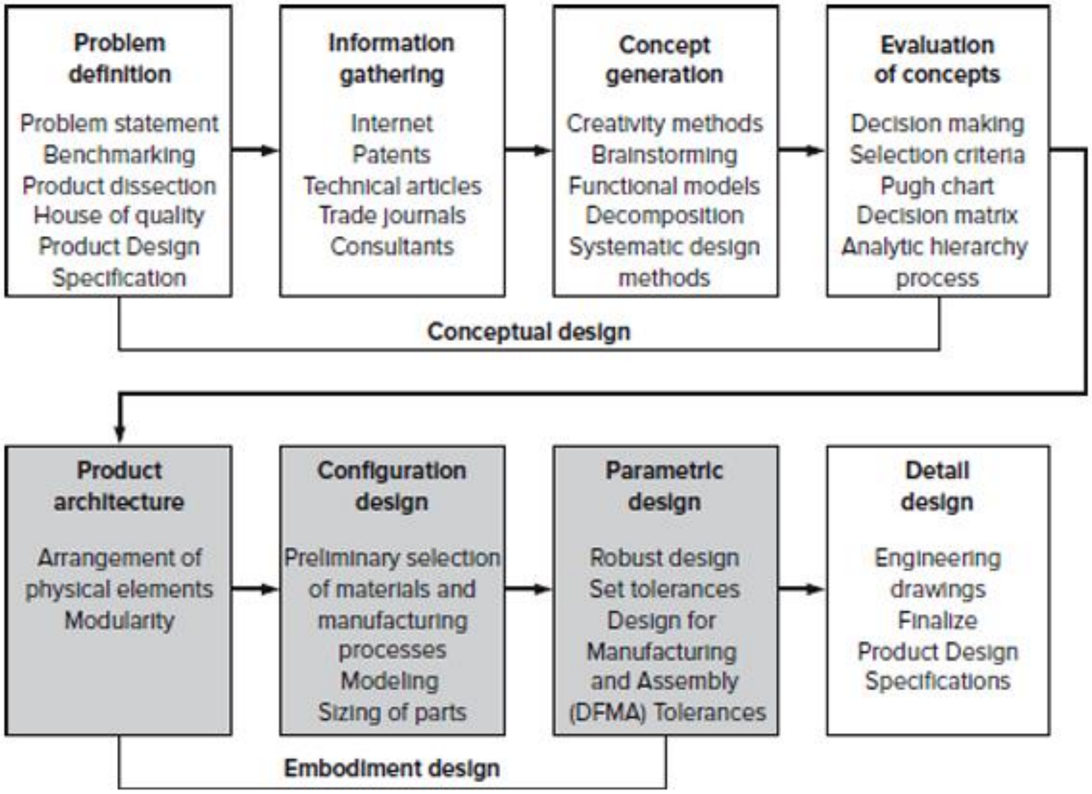

FIGURE 8.1 Steps in the design process showing that embodiment design consists of establishing the product architecture and carrying out the configuration and parametric design.

2. Three Steps of Embodiment Design (Figure 8.1)

1. **Product Architecture**
   - Defines the **arrangement of physical elements** in groupings called **modules**.
2. **Configuration Design**
   - Focuses on designing **custom parts** and selecting **standard components** (e.g., pumps, motors).
3. **Parametric Design**
   - Determines **precise dimensions, tolerances, and critical-to-quality features**.

3. Key Design Considerations

- **Dimensional Accuracy**: Ensuring proper fits and functions.
- **Aesthetics & User Experience**: Designing for **visual appeal** and **usability**.

- **Environmental Impact**: Creating **sustainable and eco-friendly designs**.
- **Additional Factors**:
    - Safety
    - Manufacturability
    - Cost efficiency
    - Performance optimization

Nomenclature in the Design Process

1. Variation in Terminology

- Different writers use different names for design phases.
- Most agree that **problem definition (needs analysis)** is the first step.
- Some consider problem definition as a **separate phase**, while others include it in **conceptual design** (Figure 8.1).

2. Embodiment Design (Preliminary/System-Level Design)

- Also called **preliminary design** or **system-level design**.
- **Term "embodiment design"** originates from **Pahl and Beitz** and is widely used in Europe and Britain.
- Adopts a **three-phase structure**:
    1. **Conceptual Design**
    2. **Embodiment Design**
    3. **Detail Design**

3. Role of Detail Design in the Process

- **Traditional Detail Design (pre-1980s)**:
    - Focused on **final dimensions, tolerances, and shop drawings**.
    - Created **bills of materials** for manufacturing.
- **Modern Detail Design (Post-1980s)**:

  - Many **dimensioning and tolerance decisions** shifted to **embodiment design**.
  - Computer-aided engineering (CAE) **moves decision-making earlier** to shorten development time and reduce errors.
  - **Detail design now focuses on information management** rather than just drafting.

4. Integration of Design Phases

- **Parametric design** determines critical-to-quality dimensions.
- **Detail design refines specifications** for manufacturing.
- **Advancements in digital tools** allow early decision-making, reducing cost and rework.

Idealization of the Design Process Model

1. Limitations of the Sequential Model (Figure 8.1)

- **The Design Process Is Not Strictly Sequential:**
  - Figure 8.1 presents the design process as a **linear sequence of steps**, moving from problem definition to final design.
  - However, **real-world engineering design does not follow a strict step-by-step flow**.
  - The process is highly **iterative**, meaning designers often **loop back to previous phases** when new information arises.
- **Need for Iteration and Refinement:**
  - At any stage, unexpected issues may force designers to **revisit and modify earlier decisions**.
  - **Example:**
    - A **failure analysis** might reveal that certain components are too weak.
    - This requires **going back to the configuration design phase** to adjust support structures.
- **Continuous Information Gathering:**
  - Information is not just collected at the beginning; **it is gathered and refined throughout the process**.

  - Late-stage discoveries (e.g., material constraints, cost limits, or unexpected performance issues) often require **revisions to earlier choices**.

---

2. Types of Engineering Design

Engineering design can be classified into four categories based on **how much new knowledge is required** and **the level of complexity involved**.

(a) Routine Design

- In routine design, engineers work with **well-established solutions**.
- **Design attributes are already known**, and the methods to achieve them are predefined.
- Often based on **industry standards, codes, and established practices**.
- **Example:**
  - Designing a **standard steel beam for a building** using **predefined structural formulas**.

(b) Adaptive Design

- Adaptive design **modifies existing designs** but does not create fundamentally new concepts.
- While the **design outcome is novel**, it is based on existing **scientific and engineering principles**.
- **Example:**
  - Taking an existing **automobile engine** and modifying it for **better fuel efficiency** without changing its fundamental working principle.

(c) Original Design

- The most challenging type of design.
- **Neither the design attributes nor the methods for achieving them are known in advance**.
- Requires **creating entirely new solutions**, often pushing the boundaries of current knowledge.
- Involves significant **research and experimentation**.

- **Example:**
    - Developing a **completely new propulsion system** for spacecraft that has never been used before.

(d) Selection Design

- Focuses on **choosing components** from a catalog that best meet the design requirements.
- May seem simple, but **selecting the right part requires careful consideration** of factors like size, efficiency, durability, and cost.
- **Particularly complex for dynamic components** (e.g., motors, gearboxes), which must be selected based on **performance characteristics like power output, speed, and torque curves**.
- **Example:**
    - Selecting a **cooling fan** for an electronic device based on airflow requirements and noise levels.

---

3. Importance of Understanding Design Complexity

- Different types of design require **different skill sets and approaches**.
- **Routine and selection design rely on existing knowledge**, while **adaptive and original design require creativity and innovation**.
- In practice, most engineering projects involve **a combination of all four types** at different stages.
- The **iterative nature of design means that even in a routine design project, unexpected challenges can arise**, requiring elements of adaptive or even original design

Product Architecture

- **Definition:** Product architecture is the **arrangement of physical elements** in a product to carry out its required functions.
- **Development Stages:**
    - Begins in **conceptual design** through function diagrams, sketches, and proof-of-concept models.

  - Fully established in **embodiment design**, where the **basic building blocks** and **interfaces** are defined.
  - Some organizations refer to this stage as **system-level design**.
- **Relation to Function Structure:**
  - A product's architecture is related to its **function structure** but does not need to match it.
  - The architecture is selected to establish the **best system for functional success** after choosing a design concept.
- **Building Blocks of Product Architecture:**
  - Typically called **modules**, but other terms include **subsystems, subassemblies, clusters, or chunks**.
  - Each module consists of **a collection of components** that carry out specific functions.
  - Architecture is determined by **the relationships among components and their functions**.
- **Types of Product Architecture:**
  - **Modular Architecture:**
    - Most common type.
    - Uses a **mix of standard modules and customized components**.
  - **Integral Architecture:**
    - Components are **highly interdependent**.
    - The system functions as **a tightly integrated whole**.
- **Importance of Module Interfaces:**
  - Critical to **product functionality**.
  - Poorly designed interfaces can cause **corrosion, wear, residual stresses, unplanned deflections, and vibration**.
  - Examples:
    - **IC engine piston and chamber**.

        - **Computer monitor connection to a desktop or laptop**.
    - **Best Practices:**
        - Keep interfaces **simple and stable**.
        - Use **standard interfaces** when possible.

8.2.1 Integral Architecture

- Functions are implemented by **one or a few modules**.
- Components often **perform multiple functions**, reducing part count.
- Can **decrease cost** unless extreme part complexity is introduced.
- Example: **Crowbar**, which provides both leverage and a handle, demonstrating **function sharing**.

8.2.2 Modular Architecture

- Each module **implements one or a few functions**, with **well-defined interactions**.
- Example: **Personal computer**, where external storage or software adds functionality.
- Benefits:
    - **Shortens product development cycles** since modules can be developed independently.
    - **Eases design team collaboration**—each module can be handled by a **single person or team**.
    - Communication between teams is **mainly about interfaces**.
- **Challenges:**
    - If multiple modules implement a function, **interaction complexity increases**.
    - Highly modular designs are often **outsourced** (e.g., **automotive seats**).

8.2.3 Budgeted Resources

- Every design has **scarce resources** that must be allocated efficiently.
- Common budgeted resources:
    - **Cost** or **performance/cost ratio**.

  - **Weight**.
  - **Space constraints**.
  - **Temperature rise** (e.g., in computer chips).
  - **Battery life and fuel consumption**.

- **Role of Product Architecture in Resource Budgeting:**
  - The first step where **resource allocation is planned**.
  - A **dedicated team member** should be responsible for **tracking and managing resources**.
  - All design team members must be **aware of their resource limits** and updated regularly.

Steps in Developing Product Architecture

- **Establishing product architecture** is the **first task in embodiment design**.
- The process involves defining **product subsystems (modules)** and determining how they integrate.
- The designer must:
  - Define the **geometric boundaries** of the product.
  - Lay out **proposed elements (parts)** within the product's envelope.
  - Allow space for **functions not yet fully defined** at the part level by using placeholders (e.g., a block holding the function's name).

Process of Developing Product Architecture

- **Establishing product architecture** is the **first task in embodiment design**.
- The process involves defining **product subsystems (modules)** and determining how they integrate.
- The designer must:
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  - Lay out **proposed elements (parts)** within the product's envelope.
  - Allow space for **functions not yet fully defined** at the part level by using placeholders (e.g., a block holding the function's name).

Process of Developing Product Architecture

- Physical parts are **clustered into groupings**, each performing a **specific function or set of functions**.
- These clusters are then **positioned and oriented** within the product's overall **physical envelope**.

Four-Step Process by Ulrich & Eppinger

1. **Create a schematic diagram** of the product.
2. **Cluster the elements** of the schematic into functional groups.
3. **Create a rough geometric layout** to organize components within the product's space.
4. **Identify interactions between modules** to ensure seamless integration.

Creating a Schematic Diagram of the Design

Purpose of the Schematic Diagram

- Ensures that the **design team understands** the basic elements required to develop an **operating design**.
- Some elements will be **actual components** that the team has already identified, while others may still be in **functional form** (i.e., not yet fully specified).

Elements in the Schematic Diagram

- **Actual components:** Recognized parts required for the design (e.g., ball return trampoline).
- **Functional elements:** Parts that are not yet specified in detail (e.g., trampoline turning mechanism).

Development of the Schematic Diagram

- Based on:
  - The **function structure** (referenced in Figure 6.6).
  - The **concept sketch** (referenced in Figure 7.4).
- **Traces flows** of energy, material, and signal from the **functional analysis** phase through the schematic.

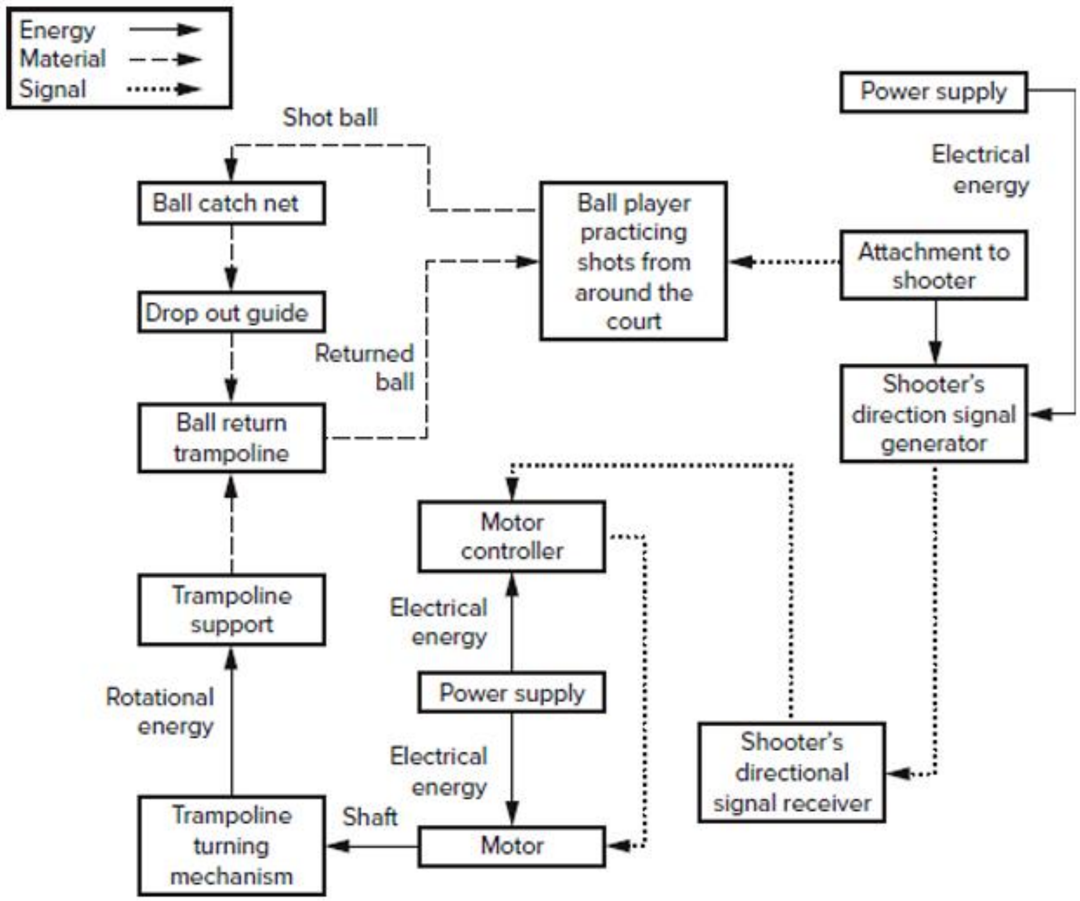

FIGURE 8.2 Schematic diagram of the Shot-Buddy showing flows between components.1 The schematic is the function structure with known components substituting functions.

Clustering the Elements of the Schematic Diagram

Purpose of Clustering Design Elements

- **Groups design elements** into clusters that will become **modules** in the final product.
- Helps **organize** the product architecture for better efficiency and **functional integration**.

Example: Modules in the Shot-Buddy (Figure 8.3)

1. **Ball Catch Module**
2. **Ball Return Module**
3. **Return Positioning Module**
4. **Return Control Module**

5. **Shooter's Signal Module**
6. **Infrared (IR) Receiver Module**

- The **IR receiver module** consists of a **single component**.
- Some modules **share components**, such as **return positioning and return control**, which share a **single power supply** (shown by overlapping modules 3 and 4).

Method for Deciding Module Formation

- **Start with each element as an independent module** and then cluster elements where commonalities exist.
- Elements are **clustered based on advantages such as:**
    - **Geometric relationships** (requiring close physical positioning).
    - **Shared functions or interfaces** (e.g., using the same power supply).
    - **Outsourcing potential** (some parts may be easier to manufacture externally).
    - **Interface portability** (e.g., digital signals are easier to distribute than mechanical motions).
    - **Flow similarity** (elements that process the same flows naturally cluster together).

Additional Factors Influencing Clustering

- **Standard part usage** (using common, off-the-shelf components where possible).
- **Future customization** (creating a **product family** that allows modular upgrades).
- **Technology integration** (ensuring **compatibility with future advancements** in design).

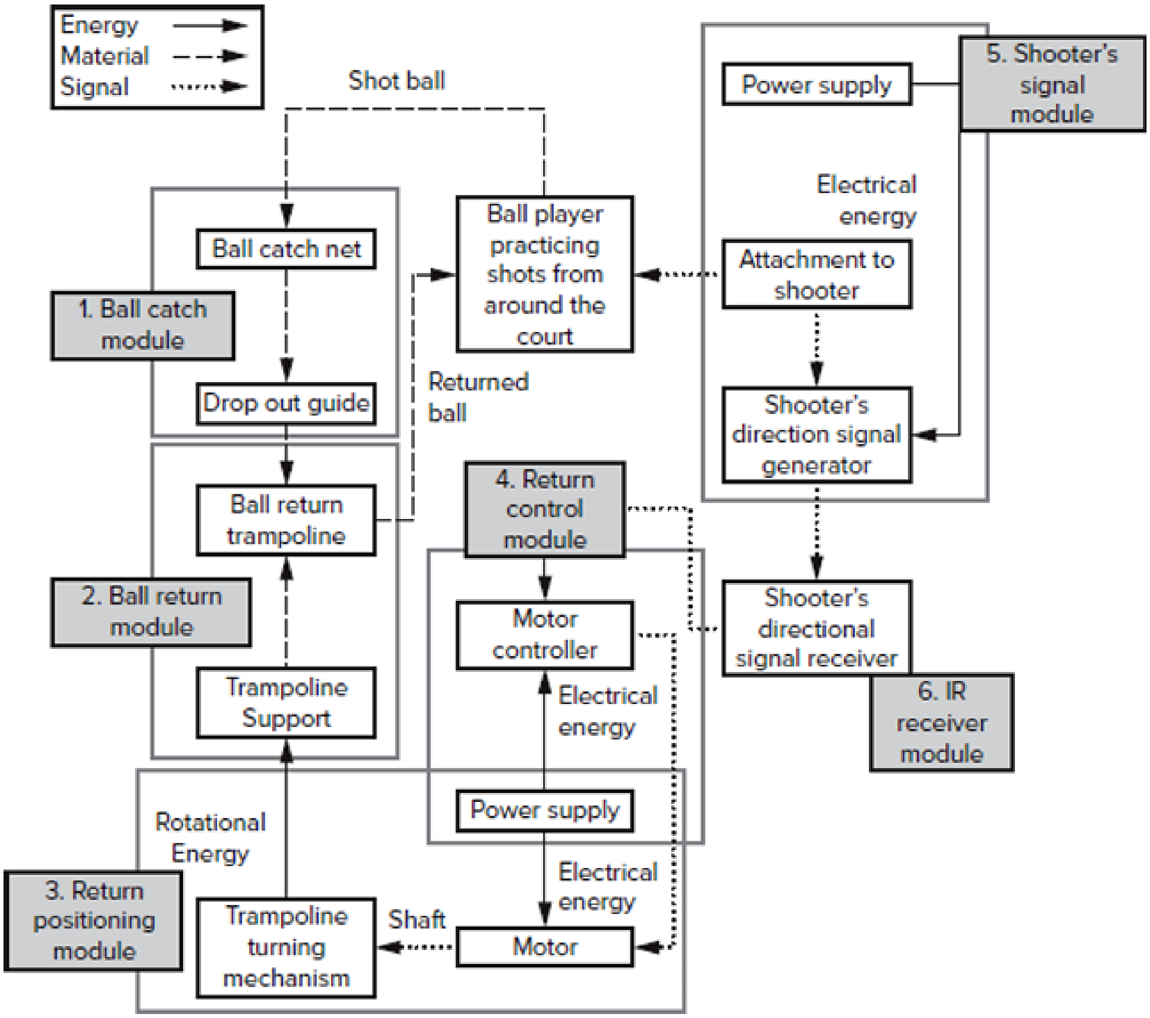

FIGURE 8.3 Schematic diagram of the Shot-Buddy showing components clustered into modules.1

Creating a Rough Geometric Layout

Purpose of a Geometric Layout

- Helps **visualize module placement** and detect potential **geometric, thermal, or electrical interferences**.
- Ensures that all modules **fit within the product's physical envelope**.
- Can be represented as a **2D drawing** or a **3D model** (physical or digital).

Example: Shot-Buddy Geometric Layout (Figure 8.4)

- **Shooter's signal module**: No physical contact with other modules.
- **Ball catch module**: Mounted on the basketball hoop and backboard (**not indicated in the layout**).
- **Ball return, return positioning, and return control modules**:
    - **Have contact interfaces**, meaning their interactions must be carefully designed.
    - **Vibration and electromagnetic interference** must be analyzed to prevent disruption.
    - **Tolerances and geometries** must be checked to ensure proper fitting.
- **Other modules**: Need to be considered in terms of **energy and material flows**, but no **direct interference** is expected.

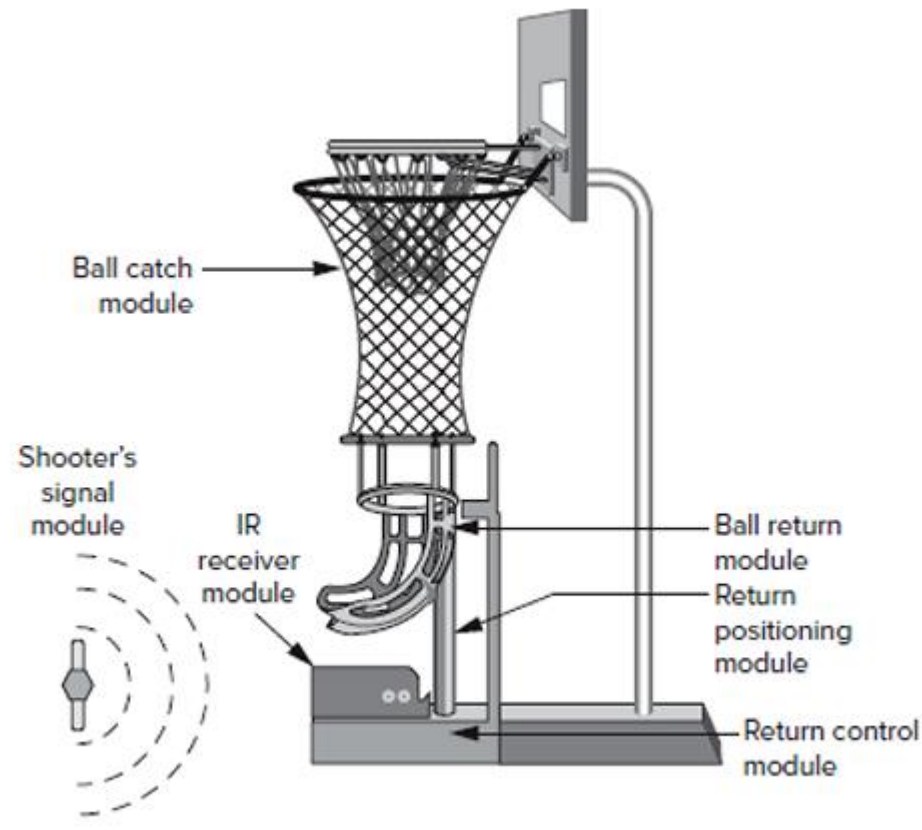

FIGURE 8.4 Geometric layout of the Shot-Buddy

Key Considerations in Creating a Geometric Layout

- **All modules should fit** within the final product's dimensions.
- **Consider interaction with external objects** (e.g., basketball hoop, backboard).

- **Indicate motion direction** to ensure **no physical interference** in operation.
- If a **feasible layout** cannot be found:
  - **Reassign elements to different modules** and try again.
  - Adjust design to **resolve conflicts** in geometry, function, or placement.

Detailed Notes on Defining Interactions and Determining Performance Characteristics

Importance of Module Interactions and Performance Characteristics

- **Core task** in defining product architecture.
- **Functionality primarily depends on interfaces** between modules.
- **Unplanned complexity** can arise at interfaces if not properly considered.
- By the end of **embodiment design**, each module must be **fully described**.

Essential Documentation for Each Module

1. **Functional requirements**
2. **Drawings or sketches** of the module and its parts
3. **Preliminary component selection**
4. **Detailed placement description** within the product
5. **Comprehensive descriptions of interfaces** with neighboring modules
6. **Accurate models for expected interactions**

Four Types of Module Interactions

1. **Spatial Interactions**
   - Physical interfaces between modules (**mating parts, moving parts**).
   - Engineering details: **mating geometry, surface finish, tolerances**.
   - Example: **Headrest and metal supports in a car seat**.
2. **Energy Interactions**
   - Flow of energy (electrical, thermal, mechanical) between modules.

- Can be **intentional** (e.g., electrical current from switch to motor) or **unavoidable** (e.g., heat from a motor).
- Both **planned and secondary energy interactions** must be documented.

3. **Information Interactions**
    - Control signals and feedback loops between modules.
    - Signals may need to **branch out** to multiple functions at once.
4. **Material Interactions**
    - Flow of material through modules when required.
    - Example: **Paper moving through modules in a laser printer**.

Independent Module Design & Team Collaboration

- **Once architecture is finalized**, module designs can proceed **independently**.
- Teams specializing in different subsystems can **work separately**, but must **maintain clear communication**.
- Example: **A power tool manufacturer with a dedicated motor design team**.
- **Module description acts as a design specification** for specialized teams.

Key Considerations for Module Arrangement

1. **Well-designed interfaces**: Ensure **proper functionality** of adjacent modules.
2. **Ease of assembly**: Components at interfaces must be **designed for efficient assembly** (refer to **Chapter 11** for guidelines).