STEM Play: Guidelines for Designing Educational Products that Reinforce STEM Concepts for Children Ages 6-18

by

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Abstract

The widespread use of the term "STEM" in education, product marketing, and industry has led to significant inconsistencies in its application—particularly in labeling products as "STEM." Without a universally accepted definition or standardized criteria, the term often fails to convey clear educational or developmental value to consumers. This thesis addresses the ambiguity by examining the current usage of "STEM" in educational and product contexts and proposes a concrete definition that incorporates learning outcomes from STEM education and the developmental benefits of play. By analyzing the intersection of STEM learning and play-based development, the study establishes a set of guidelines aimed at informing the design and evaluation of STEM products. These guidelines intend to improve product labeling clarity, support consumer understanding, and uphold the educational integrity of the STEM label.

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Chapter 1 Introduction

1.1 Problem Statement

STEM (Science, Technology, Engineering, and Mathematics) has been widely used as a term referring to educational products, practices, and highly skilled careers. However, despite its widespread use, the term has not been clearly defined and, in many cases, has been inconsistently used as a selling point for products that offer little to no educational value or relevance to other topics typically referred to as STEM. Products such as these confuse not only less-informed consumers, but also designers that lack an understanding of what STEM is and how to design appropriately labeled products.

1.2 Need For Study

In product design ideation, it is common for designers to use a process that starts with a specific task that then is researched and iterated upon. This is most famously illustrated in the double diamond design process in which designers are encouraged to follow the process of discover, define, develop, and deliver. However, when given a project brief, product designers often already have a specific goal presented to them. In this case, designers are not beginning at the discover phase in which they identify specific problems. Instead, when they are given the open-ended goal of designing a product of some type. In the case of STEM products, this is especially confusing, as STEM itself has not been clearly defined. Without a clear definition of STEM and clear parameters in which to design products, STEM product design will continue to be confusing for designers and STEM products will continue to be confusing and potentially misleading for consumers.

1.3 Objectives of Study

The goal of this thesis is twofold. First, STEM must be clearly defined to appropriately refer to its most frequent, consistent, and logical use. Second, a set of guidelines is to be created to assist designers in the development of product concepts that can be appropriately labeled as STEM products. In order to create as specific of a direction as possible while still maintaining a high degree of choice in conceptualization, the guidelines in this thesis will be targeting the initial phases of design, mainly through the creation of a clearly defined project brief.

1.4 Definition of Terms

STEM – A collection of jobs, degrees, and educational practices that focus on the application of knowledge from at least one of the fields of science, technology, engineering, and mathematics

STEM Categories – Broad fields in which tasks requiring STEM experience are common including biology, physics, geology, and other similar fields

STEM Job/Career – A job or career in which hired individuals are expected to perform a certain frequency of tasks that require STEM thinking and content

STEM Degree – A degree in which a certain amount of courses required to graduate facilitate a certain amount of STEM thinking and content

STEM Education – The learning of applied knowledge within at least one of the fields of science, technology, engineering, or mathematics

Subject – Focus, target of discussion. Does not refer to educational subjects unless otherwise stated

Science – The systematic study of the structure and behavior of the physical and natural world through observation, experimentation, and the testing of theories against the evidence obtained (Oxford, 2025)

Technology – The application of scientific knowledge for practical purposes (p.1) (Svendsen, 2021)

Engineering – The application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people (Merriam-Webster, 2025)

Mathematics – The science of numbers and their operations (Merriam-Webster, 2025)

Simulations – Activities that represent the processes of real situations (Ellington, 1981)

1.5 Assumptions

- It is assumed in this study that STEM, as it is currently used, is intended to be in reference to something beneficial.
- It is assumed in this study that a set of guidelines would be beneficial for designers who are attempting to design STEM products.
- It is assumed in this study that the term "STEM product" is in reference to a product that is educationally beneficial for the user.
- It is assumed in this study that the term "STEM product" in some way differs from the term "Educational product".
- It is assumed in this study that some products are improperly labeled as STEM products.
- It is assumed in this study that designers following the guidelines have at least minor experience with conceptualization and the double diamond design process.

1.6 Scope and Limits

This thesis focuses on defining STEM as a term, identifying tendencies in childhood learning, and developing a set of guidelines.

In order to maintain the development of a set of guidelines as the focus of study, this thesis limits details of the following areas:

Specific methods of education are not evaluated as too many variables exist within them to recommend as methods to implement into product design.

A complete history of STEM, educational practices, childhood learning, and history of product design is excluded and only the most relevant details of each are included.

The guidelines created in this thesis focus mainly on the initial phases of product conceptualization and do not expand into the future steps of project completion such as manufacturing and sales.

The guidelines recommend designing for audiences between ages 6-18. Although other age groups could be used within the guidelines, only this range is sufficiently researched.

The guidelines are specifically meant to be used by designers and design managers to assist in project brief development and product conceptualization.

The guidelines do not research trends in consumer preference in terms of product type or styles.

By limiting the scope of this thesis, more choices are afforded to designers following the guidelines while still highlighting the most important features and decisions needed to develop a successful product.

1.7 Procedures and Methods

Procedure 1: Investigate the history of STEM

Method: Library and Internet research

Record key events, people, and educational models that led to STEM as it is used in a modern context.

Procedure 2: Define STEM

Method: Library and Internet research

Collect information from different sources to find consistencies and contradictions in the way STEM has been defined in order to create a definition that is logical and appropriate to its most frequent use.

Procedure 3: Research different types of learning

Method: Library and Internet research

Record and compare different learning types in order to understand the unique benefits of each.

Procedure 4: Analyze skills considered to be valuable

Method: Library and Internet research

Record and categorize skills that are most valued by employers.

Procedure 5: Research play

Method: Library and Internet research

Collect information about play as an educational and developmentally beneficial activity. Record different types of play and their unique benefits.

Procedure 6: Investigate STEM products

Method: Internet research

Critique how current STEM products are accredited. Compare accreditation methods and accredited products to the definition of STEM created within this thesis.

Procedure 7: Create a set of guidelines for STEM product design

Method: Library and Internet research

Organize information researched in literature review to create a set of guidelines that assists designers in the conceptualization and prototyping of STEM products that align with the definition of STEM products as detailed in the literature review.

Procedure 8: Test the guidelines' efficacy of design brief creation

Method: Organization of requirements in guidelines

Create a design brief that details specific requirements of a STEM product to be designed.

Procedure 9: Test the guidelines' efficacy through product conceptualization

Method: Generate a design concept and prototype

Ideate and refine a product concept that meets the requirements detailed in the previously created design brief.

Procedure 10: Test the guidelines efficacy of evaluating product concepts

Method: Evaluate the conceptualized product by comparing it against the requirements detailed in the previously created project brief.

1.8 Anticipated Outcomes

It is expected that the guidelines created in this study will be beneficial for designers and design managers in the creation of design briefs and conceptualization of toys and games that can be appropriately labeled as STEM products.

Chapter 2 Literature Review

2.1 What is STEM?

STEM as an acronym stands for science, technology, engineering, and mathematics. However, STEM as a concept means much more than that. Instead of just referring to anything that loosely pertains to any of the four categories, STEM has its roots in education, with many K-12 and university-level curriculums being called STEM courses, careers listed as STEM jobs requiring STEM skills, and products claiming to promote STEM learning.

This is where defining STEM as a concept becomes difficult. Firstly, the broad range of topics the four categories include is loose and has a great deal of overlap if taken by definition alone. Second, the reuse of the term between education, profession, and product makes it hard to find a correlation between what makes each qualify as STEM. Thirdly, the skills gained from STEM education that are sought after by STEM careers do not always directly correlate with any of the four categories, which calls into question the role of the categories for defining STEM. Finally, there are a great deal of products that misuse the term STEM by taking advantage of the currently unagreed upon definition.

2.1.1 STEM Categories

In STEM-related discussion, the four categories are the most frequently associated topics. While association to four categories alone is not enough to label something as STEM, association to at least one of the four categories is required. This being the case, it is necessary to have a general understanding of what each category includes before labeling things as STEM. For consistency, definitions are drawn from the Merriam-Webster (2025) dictionary where most applicable, with additional definitions drawn from the Oxford (2025) dictionary where a more specific definition is required.

2.1.1.2 Science

Possibly the largest category of STEM is science. The Oxford (2025) dictionary defines science as “the systematic study of the structure and behavior of the physical and natural world through observation, experimentation, and the testing of theories against the evidence obtained”. While this covers a potentially infinite number of topics on all scales, the important part of this definition is the fact that it is specifically the study of topics, not the topics themselves. It also references the scientific method when mentioning observation, experimentation, and testing. This process can also be applied to virtually any topic, but it still does not refer to the topics themselves.

Because of the broad range of topics science could be applied to, inconsistent and loose definitions of science using these topics have led to many products being labeled as STEM. The most frequent offenders of this include anything related to space, nature, and chemicals. However, if association with any topic that could be studied was enough to define something as science-related, anything could be considered as STEM or at least STEM-related. For example, biology being the study of living things would qualify everything decorated with a plant, animal, or cell as related to science, making STEM as a term completely meaningless.

Mislabeled products that include these topics often lack the crucial defining features of science, those being the acts of studying and applying the scientific method. It is often advertised that they are STEM products because they look like they are related to what is usually thought of as a scientific topic. As mentioned, this nullifies any meaning of the term STEM. Instead, at least one defining feature of a science-related STEM product must include some form of study or scientific thought process beyond images, names, and definitions. The inclusion of these tangible learning experiences assists producers and consumers alike in the understanding of a product’s benefits rather than its association to a particular topic. This is crucial for the definition of STEM products based on educational merits (Luen, 2024).

Examples of science disciplines include biology, the study of living things and their relationships; chemistry, the study of chemicals; physics, the study of matter, motion, energy, space, and time; and psychology, the study of thoughts, feelings, and behaviors. Each one of these uses the scientific method to gain a deep understanding and solve problems in their fields of study. This is supported by the writing of Svendsen in which the nature of science (NOS) is defined by “the systematic study of the structure and actions of the physical and natural world through observation and experiment”(p.1), highlighting the observable and measurable qualities of subjects as well as the actions of participants as its primary defining features (Svendsen, 2021).

2.1.1.3 Technology

The Oxford (2025) dictionary entry for technology defines it as “scientific knowledge used in practical ways in industry, for example in designing new machines” or “machines or equipment designed using technology”. Much like the entry for science, the first implies some form of action in the creation or use of industrial machines. With how fast technology advances, limiting the definition to just industrial machines may not be enough to accurately represent modern technology. Merriam-Webster (2025) suggests broader, but more modern definitions as, “the practical application of knowledge especially in a particular area”, “a capability given by the practical application of knowledge”, and “a manner of accomplishing a task especially using technical processes, methods, or knowledge”.

Absent in any of these definitions is any reference to products or machines themselves as the defined subject. Instead, technology refers to the design of, construction of, and knowledgeable interfacing with specialized products. For any of these definitions, referencing a computer, tool, or machine as a technology itself would be incorrect. It is instead the use, programming, design, and construction of computers and industrial machines through the application of specialized knowledge that is referenced by the word technology in STEM. Therefore, for a product to be accurately referred to as STEM through the term technology alone, it must enable this action for the user and not just be a result of technological development of someone else in a STEM field.

Examples of technology disciplines are difficult to categorize on their own because of the common overlap with other STEM categories and frequent use of technological advancements. Those whose subject matter is primarily the creation and use of technology include software development, the creation of new computer programs; cybersecurity, the digital protection of data; and mechanical engineering, the analysis, development, and maintenance of physical products and systems to achieve more desirable output and higher efficiency. Each of these has a focus on the understanding and advancement of the products in their own field, often through the use of different fields of science, mathematics, and engineering. This aligns with Svendsen's definition of the nature of technology, in which it is defined as "the application of scientific knowledge for practical purposes" (p.1) (Svendsen, 2021).

2.1.1.4 Engineering

As defined by the Merriam-Webster (2025) dictionary, engineering is "the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people" and "the design and manufacture of complex products". While similar to the definition of technology, this is different because of its necessary application of both science and mathematics to achieve precise results without necessarily being restricted to industry or machines.

Examples of engineering disciplines include civil engineering, the design and construction of the public built environment; chemical engineering, the operation of and production within chemical plants; and industrial engineering, the design, organization, and optimization of all factors of a given industry with the goal of increasing productivity and efficiency. Defining features of engineering fields is the precise organization of elements to increase efficiency and output.

2.1.1.5 Mathematics

The most straightforward of the four STEM categories is mathematics. Merriam-Webster (2025) defines it as “the science of numbers and their operations”, “interrelations, combinations, generalizations, and abstractions of space”, and “configurations and their structure, measurement, transformations, and generalizations”. Simply put, this is the use of numbers and formulas to understand and plan anything that can be measured or quantified. While mathematics is used in the other categories, it is much more specific than the others and sometimes acts as a prerequisite of the others.

Common examples of mathematics fields include algebra, the use of formulas and variables to gain a better understanding of abstract problems; geometry, the study of shapes and the relationship between features of shapes; statistics, the collection, analysis, and use of numerical data; and game theory, the strategic use of mathematical models.

2.1.2 Defining STEM as a Term

As the majority of definitions of STEM categories focus on actions of study and practice rather than the results of study and practice, STEM can be loosely defined as the process of using knowledge in these categories. However, this is not a concrete definition, and it is in conflict with current STEM models, particularly because it only refers to the general study and practice of STEM. When defining a subject as a STEM job, a STEM degree, STEM education, or a STEM product, further steps must be taken to decide whether or not it qualifies as such by considering exactly how it is associated with STEM as a concept.

2.1.2.1 Review and Critique of Current STEM Models

Before agreeing upon a definition for what makes something STEM, it is necessary to analyze existing models for what STEM is as a general term and how it should be used to refer to different subjects. Common goals for the term can be implied from finding commonalities in the different ways STEM is used. These goals can be weighed against commonalities in how STEM is suggested to be implemented in jobs, degrees, education, and products to find inconsistencies and weaknesses in existing definitions. After critique of STEM models and definitions, a more appropriate definition can be made with features included that appropriately match the most commonly stated goals for the term while excluding those that create inconsistencies. Once defined, STEM as a term can be applied to qualify the categories of different careers, degrees, education, and products much more accurately than it has in the past with a much more modern relevance.

2.1.2.1.1 A Conceptual Framework for Integrated STEM Education

In their commentary article, Kelley and Knowles (2016) push for integrated STEM education, which they claim to be effective at addressing a rising need for skilled professionals that can compete on an international level. They highlight issues with STEM education that are hindering the ability of students to compete internationally by advancing their fields of study and work.

The first of these issues is the lack of connection between STEM categories. The authors claim that STEM education is often boring because of straightforward learning of individual categories, though the idea should be exciting and interesting because of the combination of multiple categories. While interest in STEM certainly would assist in student engagement and retention, the combination of two categories does not inherently increase the interest of students. Combining multiple categories may have a higher chance to include an individual subject that a student may be interested in, but by Kelley and Knowles' (2016) suggestion, the student must be interested in either both subjects or the connection between the two. Because of the difficulty of gathering accurate information on specific student interests in relation to individual and combined STEM categories and weighing that against different models of teaching, student interest should not be used to argue that the shortcomings of STEM education should have more connection between the individual categories.

The second highlighted issue further expands upon the disconnection between categories. Specifically, the authors claim that current STEM education has a large focus on science and math with "with little integration and attention given to technology or engineering". As stated, when discussing the previous issue, students are often considered ill-prepared to apply what they learn because of a lack of association between STEM categories during their education. This goes beyond individual interest and relies on individual student ability of intuition and proactivity to associate knowledge that is presented separately. While this is a major potential flaw with current STEM education, classes and curriculums that teach only one STEM category are still effective, especially when teaching prerequisite knowledge. Therefore, it would be helpful for there to be more category crossover classes in curriculums, but individual category classes do not necessarily need to be changed to enhance effective STEM education.

Kelley and Knowles expand on the disconnection between categories by writing, "STEM subjects often are taught disconnected from the arts, creativity, and design" (p. 2). With this, they highlight their strongest point: the lack of application of STEM knowledge to real-world problems. Art, as the best example, does not have any direct relation to STEM, but STEM knowledge can be applied to art. Students may not be able to associate the connection of their STEM knowledge to art on their own and instead are likely to miss the opportunity to innovate without the skills of critical thinking and problem solving skills that come with applied knowledge. The suggestion for STEM to have more of a focus on teaching applied knowledge is by far the strongest point of Kelley and Knowles and proposes an effective solution for all problems they highlighted.

2.1.2.1.2 STEM Literacy Model (Ardianto et al.)

Ardianto et al. (2018) attempt to define STEM literacy as a combined understanding of all four categories, as shown in the following graphic:

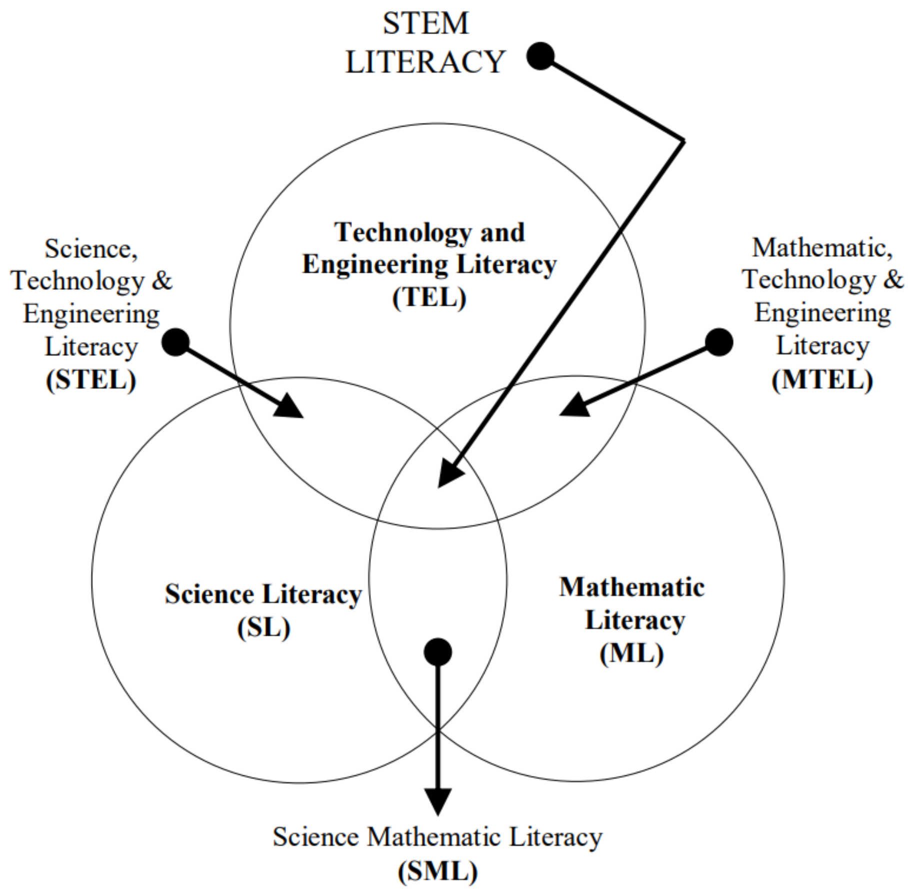

Figure 1: Model of Visualizing STEM Literacy (Ardianto, 2018)

While their definitions of each type of literacy overlapping with each other are helpful for understanding each category individually, there are a few problems that arise when presented as such.

The most apparent problem here is that of the central overlap being called STEM. The paper suggests that STEM literacy should be defined as having experience in all four categories. This is in conflict with other very common ways of defining STEM degrees and professions. The issue arises from the use of the term STEM literacy as a goal rather than simply STEM as an all-encompassing field. Math courses in K-12 and beyond, for instance, are widely considered as STEM which would align with the model presented by Ardianto et al. Mathematics degrees are also widely considered as STEM, but because the degree itself is an end goal of a curriculum, the degree itself should not be considered STEM according to this model as the degree holder is not expected to have an understanding of all of the other STEM categories. This is the same for professions that do not require literacy of every one of the four categories.

Another potential problem is the combination of technology and engineering. While this makes for a more effective Venn diagram and acknowledges the confusing overlap between the two, it fails to distinguish what makes each unique and the thought processes necessary for understanding each category in real-world use. It may be useful to group the two now that the term STEM has been accepted, but if STEM literacy is the end goal of this model, distinguishing the two to understand the overlap between them is crucial.

The last outstanding problem with this model relates to the first in the sense that treating STEM literacy as an end goal that requires literacy in all fields excludes degrees and professions that require full literacy in some or most fields as well as those that have partial literacy in all fields. This is especially apparent when this model is compared against the model proposed by Kelley and Knowles' (2016). This excludes the majority of specialized degrees and careers. Instead of this model that relies on a Venn diagram to categorize a discipline as STEM based on full literacy of all categories. Therefore, quantifying the required literacy of each category using a bar graph would be more inclusive to what are currently considered STEM disciplines.

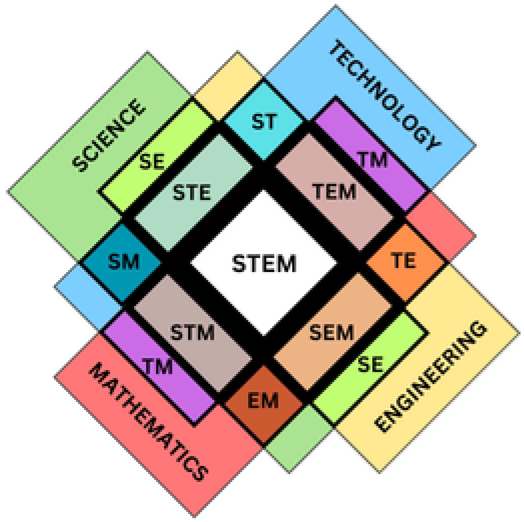

Figure 2: Conceptual Inclusive Model of Visualized STEM Literacy

An all-inclusive STEM diagram still implies that for something to be STEM, it must have an overlap between each category. These diagrams are more helpful for identifying where category overlaps may occur in subjects of discussion such as specific classes and careers.

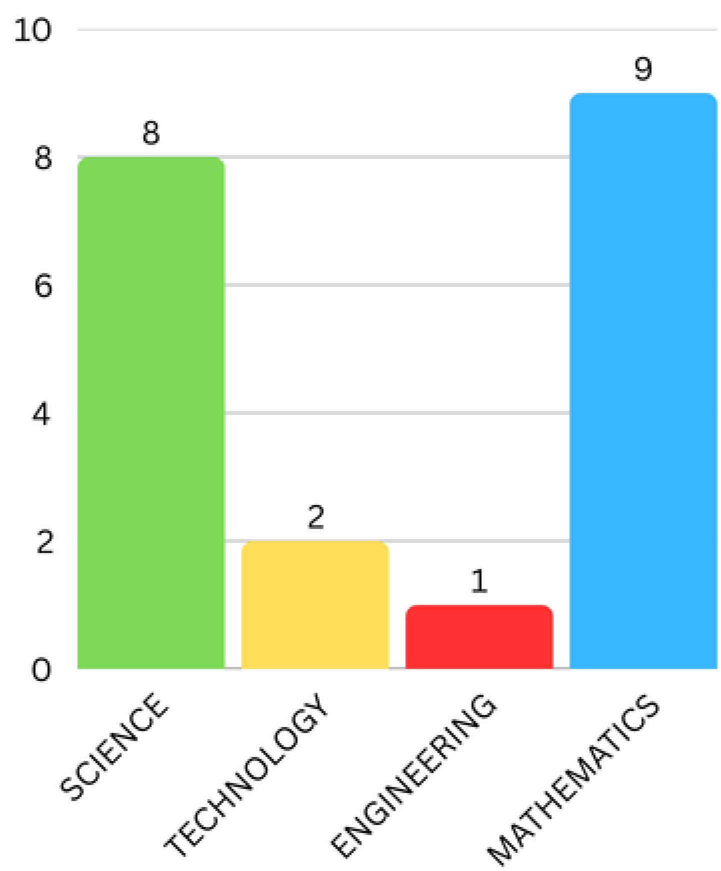

Figure 3: Conceptual Model of Qualifying Subjects as "STEM"

If a combined score of 15 is required, a degree or profession with these minimum required literacy scores would qualify as STEM with an excess of 5

This way, defining a degree or profession as STEM would require a predetermined total combined score. A generalized physics degree, for example, could be considered low in necessary engineering and technology literacy, but still be considered STEM because of its high scores in science and mathematics literacy that bring the total combined score of the degree above the STEM threshold. The method of measuring literacy proposed by Ardianto et al. (2018) may be one way of measuring these categories, though it lacks any way of measuring specific literacy scores without the use of standardized tests, making individual degrees and professions hard to score against each other. In addition, literacy scores using this method would have to measure general STEM literacy of individuals, which could have a great deal of variance from the required literacy of their field.

Instead, if a career were measured by the amount of time STEM activities are used each work week, the requirements to qualify as STEM would be much more inclusive across disciplines, without being skewed the variance of individual workers. This way, the literacy of activities is not rated because any specific activity can be defined as STEM by considering if it involves the practical application of a STEM category. Further definition of what counts as enough practical application may be required if activities are too loosely qualified. For example, an argument could be made that basic janitorial cleaning requires the knowledge that bleach and ammonia create chlorine gas and mixing of the two should be avoided, qualifying cleaning as a STEM activity and putting it at the same level of STEM as more advanced work involving chemicals such as chemical engineering.

This model still only considers degrees and professions as end goals that can be quantified and fails to consider qualifying curriculums and products as STEM. To acknowledge this issue, these categories could be classified with terms such as STEM education or STEM teaching tools. This implies that they are not objects or courses that require STEM to use, as would a tool or responsibility of a STEM qualified job, but instead are things used to help students and users gain literacy in one or more of the four categories so that the knowledge gain can potentially be used later in a qualifying STEM discipline. However, this poses another need of differentiating STEM-specific learning tools and generalized learning tools, as highly generalized skills could potentially be used in any field, STEM or otherwise.

2.1.2.1.3 STEM Definition Findings

The most common current goals for STEM as a term are organized as follows:

1. STEM should refer to anything that includes at least one of the four STEM categories
2. STEM should refer to anything that includes at least two of the four STEM categories
3. STEM should refer to anything that includes all of the four STEM categories
4. STEM should refer to applied knowledge of at least one of the four STEM categories
5. STEM should refer to applied knowledge of at least two of the four STEM categories
6. STEM should refer to applied knowledge of all of the four STEM categories

As seen from the STEM literacy model of Ardianto et al. (2018), defining something as STEM based on the requirement that it includes something from all four categories is too restrictive and is nearly impossible to apply to many subjects that are currently considered STEM, such as mathematics education as a career and any other intradisciplinary subject. This means options 3 and 6 from the list above should not be considered accurate STEM definitions. Similarly, options 2 and 5 can be excluded for the same reason, as defining STEM as the connection between two categories in a single interdisciplinary subject is less restrictive, but still not inclusive to other intradisciplinary subjects that are crucial to understanding the previous. For example, 2 and 5 would consider physics a STEM degree, but mathematics and science classes would not be. Option 1 should be excluded for the opposite reason to the previous four; that being the fact that it is too inclusive. If option one was an appropriate definition, anything themed as one of the four STEM categories could be considered STEM, which fails to consider the active nature of definitions of the categories themselves. A case could be argued for virtually any subject to be considered STEM-themed by the definition of option 1. Therefore, option 4 is the most appropriate. STEM being defined as the applied knowledge of at least one of the four categories appropriately includes interdisciplinary jobs and degrees as well as the intradisciplinary educational activities and products that are needed for those jobs and degrees.

This definition also excludes superficial relation to the four categories as a defining feature of any subject as it relies specifically on the act of applying knowledge, not the act of gaining knowledge.

This differentiation also acts to clear up a common question in STEM discussion: should classes that teach a STEM category be considered STEM? While gaining knowledge may be necessary for its application, anything themed as a STEM category could be argued as sharing STEM knowledge for memorization and future use but, as presented in the discussion of option 1, this includes potentially everything as every profession and discipline could be argued to relate to at least one STEM category. Moreover, memorization alone does not inherently imply the application of the memorized knowledge, disqualifying classes, products, and all other subjects that do not directly enable or demonstrate the application of STEM knowledge.

Similarly to the fact that STEM categories and non-STEM categories can be differentiated, STEM knowledge and non-STEM knowledge can also be as well. For example, critical thinking is a commonly referenced skill in STEM discussion, though critical thinking classes of non-STEM categories should not be qualified as STEM as they do not explicitly demonstrate the use of knowledge from at least one category. If it were to be qualified, there would be no restriction of what level of knowledge or thinking skills should or should not be considered STEM, as any elementary knowledge, such as the ability to read and write, are technically prerequisites to the understanding and practice of physics.

Therefore, STEM can be defined as such:

STEM - A collection of jobs, degrees, and educational practices that focus on the application of knowledge from at least one of the fields of science, technology, engineering, and mathematics.

With this definition in mind, more accurate definitions can be created for the terms STEM job, STEM degree, STEM education, and STEM products.

2.1.2.2 Defining STEM Jobs and Degrees

In their conceptual framework for integrated STEM education, Kelley and Knowles (2016) detail skills and standards common to STEM practices. These are organized into three tables that act in their article to highlight commonalities between STEM practices in order to justify using the intersection of STEM content and practice as a reference point to assist STEM educators. Alongside achieving this, the collection of these skills and standards in this way is also able to be used to set standards for and qualify jobs and degrees as STEM. For instance, to qualify a physics degree as STEM, holders of said degree must be able to perform tasks that require a certain degree of STEM education. However, this poses a couple questions about how to accurately qualify these degrees. First, should there be a number or frequency of skills that act to define a degree as STEM? Next, should the degree of difficulty of necessary tasks be a qualifying feature of STEM degrees and, if so, how is the degree of difficulty decided upon?

Using the combined course requirements of any given degree, expectations can be formed about the abilities of students graduating with said degree. The depth and difficulty of classes vary with the depth and level of the degree. Because there are different levels of degrees in the same field of study that all qualify as STEM, difficulty or amount of literacy required is not an accurate measure of whether a job or degree can be qualified as STEM. Instead, the frequency STEM thinking is used within a particular degree's classes is a more accurate way of qualifying that degree as STEM. As of now, there is no standard for either defining degrees by amount of STEM classes or classes or defining classes by frequency of STEM thinking. Instead, curriculums are defined as STEM much more subjectively based on if they appear to be "STEM-like" enough. If there were a stricter way of qualifying a degree as STEM, a similar method could be used for qualifying jobs as STEM based on the job's requirements and expected duties. Due to the lack of any widely agreed upon definition, for the purposes of this study, STEM jobs and degrees are defined as follows:

STEM Job - A job in which hired individuals are expected to perform a certain frequency of tasks that require STEM thinking and content

STEM Degree - A degree in which a certain amount of courses required to graduate facilitate a certain amount of STEM thinking and content

The purpose for separating STEM degrees and jobs from STEM education and STEM products is so that the degrees and jobs are treated as terminal points. They are end goals that can be qualified based on the requirements of individuals rather than a process that an individual is going through or an object that is being used.

2.1.2.3 Defining STEM Education

To make the distinction between STEM educational tools and generalized non-STEM educational tools, the main focus of the subject's educational process must include the application of learned knowledge or skills to at least one of the four categories to be considered STEM education. For example, a critical thinking course using hypothetical legal decisions would lack any direct STEM application and therefore would not be considered STEM education while a critical thinking course about medical diagnoses would have a direct application of a STEM category and therefore would be considered STEM education.

Alternatively, if the main focus of the subject's educational process does not include any generalized skills, it is possible for an educational tool or course to include STEM subjects as its main focus. As memorization of STEM-related knowledge directly increases literacy, defining any subject that teaches such knowledge as STEM would make sense at first thought, but this being the sole defining feature of qualified STEM education would include everything that matches the vague definitions of the four categories. Instead, it would be more accurate to define STEM education as the inclusion or introduction of at least one STEM category with some form of implied practical application if not the application of a practical skill in the context of at least one STEM category. Either way, STEM education must include both content and context to separate itself from non-STEM skill-based education and memorized knowledge of STEM categories. As previously stated, the learning of skills without any connection to any STEM categories and learning of non-applied knowledge within STEM categories may be prerequisite to STEM education, but cannot themselves be classified as STEM education as there is no guarantee or expectation that the knowledge or skills learned will be used in the application of a STEM category. Understanding this distinction is also crucial when considering the labeling of products as STEM, because their primary implied purpose is to assist with STEM education. Because defining STEM education as "education within the realm of STEM" is too loose, for the purposes of this study it will be defined as follows:

STEM Education - The learning of applied knowledge within at least one of the fields of science, technology, engineering, or mathematics

2.1.2.4 Defining STEM Products

In order to understand the implications that STEM has for product design, it is first necessary to define what each category includes. These definitions help to distinguish each category from one another as well as limit what does and does not qualify as STEM. In order to avoid overlap between categories, a presented topic can be categorized by the most relevant category or further broken into subcategories that are more distinguished by discipline (Kelley, 2016).

In discussion of STEM categorization, jobs with multiple responsibilities and objects with no context of human use and interaction are difficult to define in a single category. For example, circuit boards as an object alone imply many STEM categories. As the most related activity to the object itself, the act of circuit board construction may be defined as engineering since the activity of creating a circuit board mostly requires an understanding of precise construction of circuit boards. However, the acts of operating and programming of circuit boards may be defined as technology because of their wide range of innovative uses and role in modern technology. Furthermore, study and use of the chemical properties and possibilities for innovative improvements using different materials in circuit boards could be considered as science. Finally, the calculating and controlling of electric circuits within the circuit board would undoubtedly fall under mathematics. Because of the potential overlap between objects and concepts, specific activities are better to use as subjects of discussion.

This ties back to the definition of STEM education. It is not enough to define something as STEM if some part of it is related to a STEM category (Ardianto, 2018). Instead, STEM as a term more accurately refers to something that involves the human application of science, technology, engineering, and/or mathematics. Similarly, STEM products as a term refers to those that promote the development of the practical application of learned skills or knowledge in said fields. This aligns with many existing products being labeled as STEM products. It is usually implied by the packaging of these products that they in some way assist in STEM education. However, many products that this study considers mislabeled STEM products are only decorated or themed in a way that is tangentially related to a STEM category, such as a set of dinosaur toys that are claiming to be STEM because of their connection to science through paleontology without any implication of how to apply any knowledge related to a STEM practice. There could be an argument that products such as these may be classified as STEM themed, but for one to be a STEM product would require the education of applied knowledge through use, not the education of knowledge or skills alone. To better make a distinction between products, STEM products will be defined as follows:

STEM Products - Products that, through use, demonstrate applied knowledge within at least one of the fields of science, technology, engineering, or mathematics

This definition excludes many useful educational tools such as rulers and protractors that may assist in learning within a STEM category but lack any self-contained application that can be acted upon by the user. Also excluded are products such as flash cards and posters that may have useful terms or definitions that can be memorized but also lack any self-contained application of this knowledge. Calculators, however, would be an example of a STEM product because of a user's ability to use the calculator to learn to practice mathematics without any necessity of outside guidance.

As STEM products as a term has not been used accurately to how it is defined here, it is difficult to gauge the helpfulness this definition has to the concept of STEM without examples to draw from. Fortunately, analyzing similar subjects presents an opportunity to understand the value of defining STEM products this way. Models, for instance, are learning tools that are often used to assist education in a very similar way to many STEM products on the market today.

2.1.2.4.1 Examination of modelling in K-12 STEM teacher education: Connecting theory with practice

In their article in the American Institute of Mathematical Sciences, Martinović and Milner-Bolotin (2021) advocate for the creation of physical models as a useful tool in STEM education, potentially seeing more success than other methods due to models assisting students in understanding real life situations. A graphic of their proposed method to implement models in mathematics education is shown below.

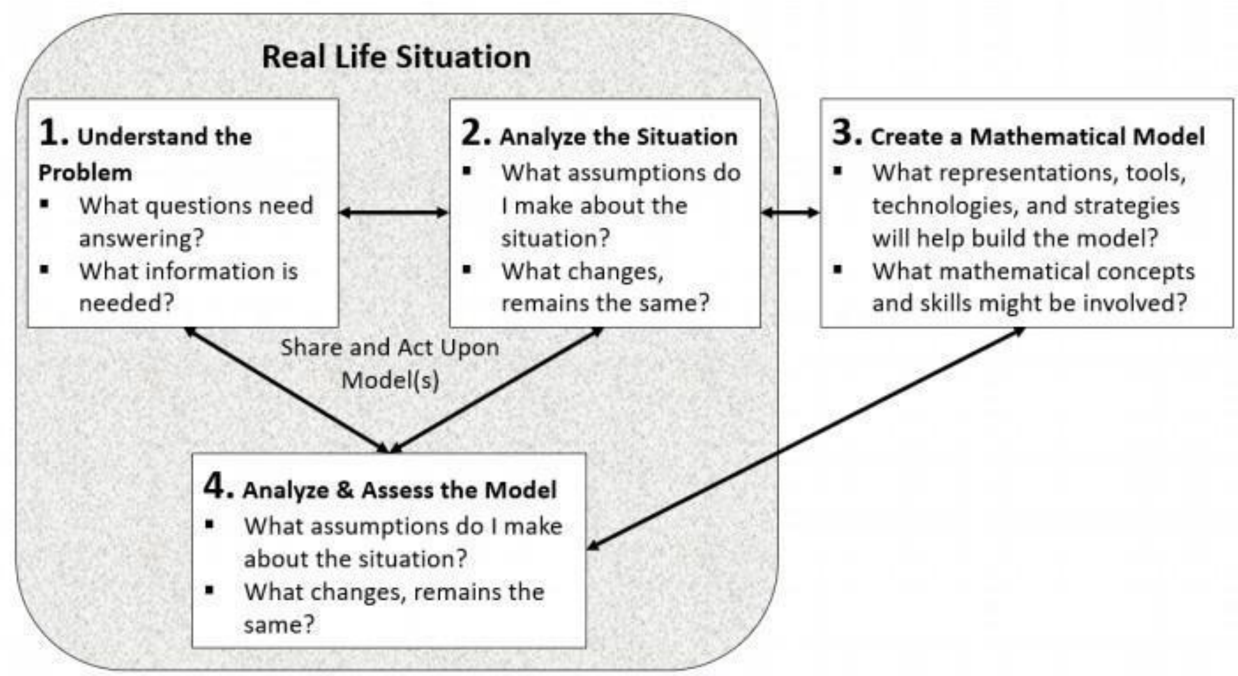

Figure 4: Diagram of Educational Opportunities of Models (Martinović, 2021)

While applicable to all STEM learning, Martinović and Milner-Bolotin use mathematics as an example for their method because "mathematics curricula have paid limited attention to helping students develop modelling skills" (p. 282) even though modeling, design, and experimentation are all core methodologies in the STEM workforce. Their research highlights the value that STEM products bring to students. When considering a STEM product as a model of the concept it represents, it can be used in a similar way to assist learning as models are in the figure above. However, products treated as models are not created by the user to understand an existing problem. Instead, they exist to introduce and familiarize users with concepts. Because of the way they are used to spark and guide learning rather than assist and enhance learning, the place STEM products appear in the order of the learning process is reversed from the model above. The figure below is more representative of where STEM products fit into the learning process.

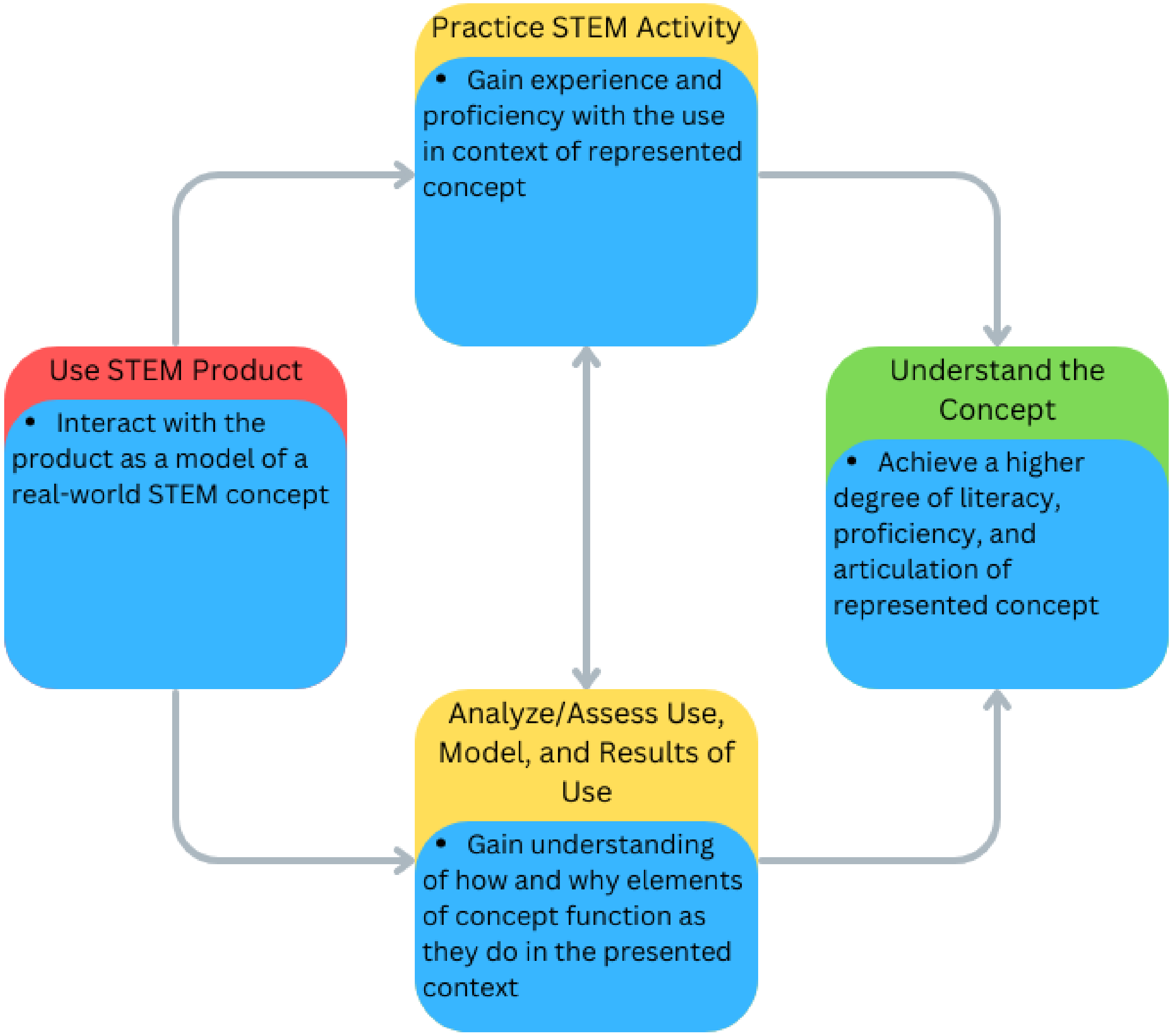

Figure 5: Model of STEM Product Learning Process

Because the case-by-case use of different products varies so greatly, the figure above focuses on the learning outcomes of each step in practice (shown in blue) rather than the actions or thought processes highlighted in the previous figure. The conceptual understanding gained from STEM products assists students in using and understanding models in the future, enabling them to ask the questions presented by Martinović and Milner-Bolotin and formulate faster and more appropriate answers (Martinović, 2021).

2.1.3 History of STEM

STEM as a term is relatively new. It has its roots in earlier models of education and is currently transforming as people try to further define and expand upon it. As can be seen in the fact that there is no solid agreed upon definition, some changes to the model such as the addition of art make the application of STEM loose and confusing. As such, it is important to understand what changes are being made as well as how STEM has evolved over time so that a stricter definition can be agreed upon to be more accurately applied to disciplines, education, and products than it has been in the past.

2.1.3.1 Organizational Behavior

One of the earliest models for structuring efficient and competent employees in the workforce is organizational behavior. In the early 20th century, Frederick Winslow Taylor sought to improve efficiency in the workplace and, through what he called scientific management, found that people in management positions had the ability to improve the efficiency of their workers by making changes to the workers' environment and equipment. He first did this Bethlehem Steel Company where he tested different lengths of shovels to find the most optimal average shovel that could be provided to workers. Once the optimal shovel was found, he suggested that the company provide this type of shovel to its workers rather than making them bring their own as they had done before. This resulted in a notable increase in efficiency for the company (Gorman, 2003).

The success of Taylor's study suggests two very important findings that led to the eventual development of the concept of STEM many years later. First is that workers perform more efficiently at their jobs when they are better prepared to perform them. Second is that workers that are equally prepared to perform the same tasks in the same environment can be compared against each other on their own merit. This is very similar to the way that STEM is treated today. Many treat STEM education as valuable because it, in theory, gives future workers the mental equipment to perform tasks at a higher level of skill and efficiency at the time of them being hired than they would without. Because of this, there has been widespread desire for public education to be standardized so that students can compete on an equal playing field. Possibly the most successful attempt to standardize education is the concept of Common Core.

2.1.3.1 Common Core

Common Core State Standards (CCSS) started in 2009 as an attempt to give public school students a standardized education by using highly controlled tests and curriculums. Standardized tests such as the SAT and ACT already existed, but CCSS functioned within K-12 curriculums so that, in theory, students would graduate high school with a nationally common level of experience. In practice, CCSS was a frequent subject of controversy, with educators often disagreeing with the structure of the strict curriculums being handed to them. One key problem was that because curriculums were already formed before reaching educators, decisions on what knowledge, experience, and skills were deemed necessary was already decided, with any additional knowledge, experience, and skills being treated as extra and therefore unnecessary. Educators often found that they did not have the time to teach what they considered crucial prerequisites because of the heavy time consumption of the CCSS curriculums they were required to teach (Supovitz, 2017).

Although the objective of CCSS is to give students a more equitable starting point when entering higher education and the workforce, the success of curriculums such as these requires extremely strict control of educators, students, and learning environments at all levels. CCSS also fails to account for variations in individual learning such as a single student not fully understanding course content due to the failure of an educator to properly communicate a particular concept (Supovitz, 2017). Instead of standardizing entire curriculums with a heavy reliance on previous education, STEM education tends to have a higher focus on individual concepts being taught fluidly so that students have more room to explore concepts on their own rather than at the predetermined pace of a curriculum their educator has little control over. This was not always the case, though, as the first concept of STEM was very similar to CCSS in the way it was conceptualized to teach prerequisite information in a specific order.

2.1.3.2 SMET to STEM

The earliest concept of STEM was conceptualized by the United States National Science Foundation (NSF) in the 1990s as another acronym - SMET. The letters S, M, E, and T were originally organized this way to imply the order for which they are introduced into the learning process. Scientific concepts were the main subjects and broadest category. Mathematics was meant as a means to solve scientific problems and lead to solutions through engineering and the knowledgeable use of technology. The desire for this type of learning to be taught in schools traces back to the space race where the fields of science, technology, and engineering became publicly trendy. One problem with this model is that it relies on the interconnection between the categories. Unless a job or class has a focus on this interconnection, it would be difficult to justify the job or class as qualifying as SMET unless it was a prerequisite class that was in a structured curriculum that overlapped categories later (Pruitt-Mentle, 2021).

In 2001, SMET changed to STEM. The most frequently cited reason for this change is that the acronym SMET sounded too much like the word smut and just generally sounded "gross". To further justify the change, Judith Ramaley (2001), often cited as the one who coined the term STEM, had this to say on the subject:

> In STEM, science and math serve as bookends for technology and engineering. Science and math are critical to a basic understanding of the universe, while engineering and technology are a means for people to interact with the universe. STEM weaves those elements of human action and understanding into all aspects of education. (p. 7)

While a very poetic explanation, the main benefit of the switch is that STEM was now trendier and could gain more popularity and respect. However, this came with the downside of losing the previously intended structure for connecting the four categories. After the switch, STEM started to become much vaguer, often including anything that tangentially related to the four categories and leading to the current abuse of the term to improperly add perceived value to products and education. This is due to the use of a simple acronym constructed using simple terms. It is easy for one to imply meaning from STEM and improperly qualify various things by nothing more than vague association to at least one category. This is what is frequently done by students, educators, parents, companies, marketing teams, and others, arguably more often than not.

Another downside comes with the combination of the inherent vagueness of the term STEM and the desire of "STEM" supporters for the term to be accepted as valuable. After STEM had been presented as Ramaley and many others had, classes, curriculums, and products began to be labeled as STEM as if it were a catch-all adjective. This means that some things were STEM and some things were not. Since STEM is so broad, this implied that these subjects could also be seen as "technical" or "for smart people" if they were considered to be STEM or "not as valuable" if they were not. This way of thinking changed the way subjects such as literature and social sciences were treated, being given lower priority to STEM subjects, and educators attempting to justify many classes as STEM without much of a connection to any of the four categories. Eventually, there was a great deal of pushback on this duality of implied value of STEM versus implied unnecessaryness of non-STEM. This pushback is still ongoing but is leading to a further loss of meaning for STEM.

2.1.3.3 STEM to STEAM

The exclusion of art from STEM was one of the main points of controversy for the term. To combat this, some began to use the term STEAM (Science, Technology, Engineering, Art, and Technology). Because STEM is already very vague, the addition of art does not necessitate the overlap between art and any other category of STEAM. This means that if a job, degree, class, product or any other subject was not considered to be technically focused, it could be justified as artistic. The problem with this is that anything could be justified as vaguely related to science or art, as anything can be studied, practiced, or experienced. This removes all meaning from the concept of STEAM, though many use the term in tandem with STEM to add perceived value to different subjects. Because of the lack of structured meaning of the term, STEAM will not be suggested as bringing any value for the purposes of this study.

2.1.4 Value and Perception

With the rampant use of the term STEM comes the expectation that the labeled product or educational experience is valuable in some way, although exactly what value specific subjects bring is often assumed or not readily apparent beyond learners gaining experience with the content. Understanding the more specific learning outcomes of STEM subjects would further and much more accurately justify their creation and use.

2.1.4.1 Expectations of STEM

The results of STEM education vary with many different factors. A meta-analysis study conducted in 2023 concluded that in addition to specific subjects being taught, the results of STEM programs varied heavily based on both the structure of problem-based learning (PBL) models and the grade level of participating students. The success rates recorded by the study are extremely helpful for justifying STEM programs, claiming that there are three main types of learning - cognitive, collaborative, and content learning (Suciana, 2023). These learning types align with how STEM products are advertised to benefit users. Although rarely specific, they often claim to help develop cognitive skills while also giving experience with the presented content. If there were to be a specific learning objective of a STEM product, the design of that product would have to consider the type of learning experience best suited to impart the desired knowledge, skills, and experience upon the user.

2.1.4.1.1 Types of Learning

To understand the possibility for STEM education in product design, one must consider the different types of education as well as the learning outcomes of education. With each type of learning comes different opportunities and methods to achieve different educational results upon the learner, so the ability to craft the most appropriate learning experience is essential for STEM product design. One model for breaking down different types of learning with different opportunities and benefits is that of formal, non-formal, and informal learning, as written about in a research report from Cambridge University Press and Assessment (Johnson, 2022).

2.1.4.1.1.1 Formal Learning

Formal learning is usually associated with structure. While sometimes flexible, the structure of formal learning comes from a predetermined plan for timeframes, lessons, and activities that come together to form a curriculum. Because of the standardization of formal learning, learning outcomes and individual success of students are more easily measured. Because of this, it is the most commonly used form of learning in public schools. Common learning outcomes include memorization of generalized knowledge and procedures, efficiency, and experience with concepts that are often prerequisite to future learning. Common downsides of formal learning include motivation to learn and participate not being inherent to the student, lack of flexibility in the activity or curriculum, and lack of soft skill building through socialization. Put simply, formal learning has a strong focus on building intelligence and knowledge of course content, but not necessarily the wisdom to use this knowledge creatively (Johnson, 2022).

2.1.4.1.1.2 Non-Formal Learning

Non-formal learning is more flexible than formal learning. It has more emphasis on the student's interests and needs, rather than the strict structure of the curriculum itself. Because of this, non-formal learning tends to be much more inclusive and accessible to those with special needs and is useful for developing practical skills for the student. This type of learning is best used when intending to teach critical thinking skills rather than generalized knowledge. Its flexible nature lends itself to more equally building intelligence through taught knowledge and the wisdom to use this knowledge in creative ways outside of the context of the curriculum (Johnson, 2022; Rizova, 2020).

2.1.4.1.1.3 Informal Learning

Informal learning is the hardest to define, as it is not usually seen as controllable and is often used interchangeably with the term non-formal learning. It is most often used in reference to knowledge gained from everyday experiences or experiences outside of any curriculum or designed educational experience. Informal learning relies on prerequisite knowledge and ability to function in a given setting to learn by oneself through experimentation and discovery. Much like informal learning, it can be used to great effect to impart both intelligence through memorized knowledge and wisdom of contextual knowledge and critical thinking skills. However, because STEM product design implies some level of crafted educational experience, informal learning is not recommended to inform STEM product design in this paper despite users' potential ability to use a product in an unintended, informal setting (Johnson, 2022).

2.1.4.1.2 Results of Education

Results of education can be classified into two categories - practical and social. Often described as hard and soft skills, these differ in a similar way to the way types of learning do. When designing a product, understanding the difference between the two is essential for the designer to have better control over deciding on specific learning outcomes and imparting those upon the user.

2.1.4.1.2.1 Practical Skills

Practical skills, or hard skills, include both memorized knowledge of a subject and the ability to use that knowledge in practice. These are most often learned first through formal learning before being put into use later in non-formal or informal learning. Put simply, practical skills are what define the measurable abilities of an individual within a given context (Linton, 2019).

2.1.4.1.2.2 Social Skills

Social skills, or soft skills, refer to the ability of an individual to interact with others effectively as well as the ability to think and act creatively. This often requires prerequisite memorized knowledge to act on but can also simply be the knowledge of how one should and should not act in a given setting. Individuals with developed social skills often display higher efficiency and creativity than those without in similar settings. Common soft skills include critical thinking, effective communication, teamwork, leadership, and problem solving (Ibrahim, 2017).

2.1.4.2 Most Sought After STEM Skills by Employers

While all skills have the potential to be valuable, some are able to be used in a wider range of situations and have a greater impact on workplace efficiency than others. In order to better inform the design of learning experiences and better justify their use and creation, it helps to understand what skills employers value from STEM education. Common STEM skills sought after by employers are demonstrated in a 2020 study conducted to "identify employability skills lacking in the STEM industry" (McGunagle, 2020).

2.1.4.2.1 Experience and Proficiency

Most apparently, competency in required tasks is crucial for employment, though specific knowledge of content and knowledge of operations within one job are highly dependent on the job itself. Therefore, it is uncommon to see specific skills such as chemistry or engineering experience listed in studies such as these. Instead, experience and proficiency should be treated as key requirements rather than helpful bonuses, as they would in a job application process. They are most often gained through formal learning and may act as the primary focus of educational content or as the backdrop of prerequisite knowledge as other associated skills are taught (McGunagle, 2020).

2.1.4.2.2 Interpersonal Skills

One category of skills valued by employers can be classified as interpersonal skills. These are soft skills that are among the most valued of all with the most common examples being teamwork, verbal communication, and presentational skills. It is interesting to note that none of the skills in this category are dependent on STEM-specific knowledge and are possible to be learned outside of STEM entirely. However, it is possible to hone non-STEM-exclusive skills to be used to much greater effect within the context of STEM. For example, one may be experienced with presentations in general but may not be experienced with knowing how to present scientific data more effectively by knowing what specific data to draw attention to and how to talk about it. This more specific skill would be considered STEM education, while the learning of generalized presentational skills would not. Regardless, presentational skills of any degree are valued in STEM fields (McGunagle, 2020; Petersen, 2020; Robles, 2012).

2.1.4.2.3 Individual Skills

The other category of skills valued by employers is individual skills. Put simply, these are non-contextual skills that are not reliant on any interaction with other people and instead act to increase personal efficiency and competency in the workplace. The most commonly sought after of these skills include self-motivation, critical thinking, problem-solving, proactivity, and adaptability. Much like interpersonal skills, these skills are not STEM-specific. However, unlike interpersonal skills, skills such as critical thinking, problem solving, and adaptability require contextual knowledge to be used at full efficacy (McGunagle, 2020).

2.2 Play

While the most apparent learning experiences are those that appear in classrooms, playing is just as, if not more, effective at imparting skills and knowledge than traditional learning experiences. It also has the implied benefit of creating some amount of interest, theoretically improving the engagement of the user and enhancing the learning experience.

2.2.1 Benefits of Play

For a long time, play has been respected for use in educational practices, though not all benefits of play are readily apparent. For instance, toys and games that are not specifically marked as educational can still bring developmental benefits. Coincidentally, the lack of calling out developmental skills that can be achieved through play with toys and games comes with the opposite effect as STEM products are being improperly labeled as bringing educational value.

2.2.1.1 Practical Skills and Knowledge

The most obvious and quantifiable benefits of play are practical skills and knowledge. These are gained through memorization of content and tasks, which is much more of a natural process during play than it is through traditional education. The results from a collection of sixty-six game-based learning studies indicates that the main reasons for the high success rate of play to teach children is due to play's tendency to increase involvement, demonstrate information in unique ways, and cater to individual needs and interests (Annuar, 2024).

2.2.1.2 Social Skills

Social skill development is the most commonly noted benefit of play. Researchers state that "games are often designed to promote social interaction and teamwork" (Annuar, 2024). Beyond this, technology is often used cooperatively to achieve goals, increasing user literacy in a natural setting rather than in a classroom with a predetermined goal (Annuar, 2024).

The most notable benefits of social skills developed through play include communication, emotional control, and cooperation. These directly align with the soft skills that are most valued by employers. Furthermore, the familiarity with the experienced subject matter and situational comfort gained through play assist in giving children a more natural-feeling and effective learning experience (Aljunaidi, 2023).

2.2.1.3 Autonomy

The ability to think and act by oneself leads to more effective learning and retention of knowledge, hard skills, and soft skills. Play has been shown to increase autonomy in children by encouraging children to act on their own while forming their own preferences in a setting that encourages free choice rather than following guidelines (Burke, 2023). One of the main factors that enhances autonomy through play is play’s tendency to increase users' interest and involvement. This leads to a higher engagement rate that results in cognitive development of critical thinking skills, problem solving abilities, and creative abilities (Annuar, 2024).

2.2.2 Montessori Education Age Ranges, Needs, and Learning Opportunities

Because of its well-documented educational uses, play has been a part of many educational practices. One of the most famous and most commonly implemented in early education is Montessori Education. Founded by Maria Montessori, this style of teaching children uses children’s personal interests to motivate them to not only associate that interest with learning, but also retain key developmental skills, including cognitive, social, and practical skills. In order to best cater to the individual needs of children, Montessori has defined age ranges all with different developmental needs and opportunities for learning (Mavric, 2020).

2.2.2.1 Ages 3 to 6 - Preschool Education

From ages 3 to 6, Montessori education recommends focusing on sensory exploration and motor skill development. Because of this, it is strongly recommended that activities are designed to be hands-on utilizing various materials. Key learning objectives for this stage include development of creativity, interest-forming, physical autonomy, cognitive autonomy, and early social skills (Murray, 2023).

2.2.2.2 Ages 6 to 12 - Middle Childhood Education

From ages 6 to 12 children develop more complex cognitive functions. Successful teaching methods for this age group often have a focus on collaboration and peer learning through the use of group discussion and collaborative problem solving. This age group also marks the beginning of a child's exploration of interdisciplinary concepts. Key learning objectives for this stage include cognitive flexibility, self-regulation, problem-solving, and critical thinking skills as well as the learning of more complex information through memorization (Murray, 2023).

2.2.2.3 Ages 12 to 18 - Adolescent Education

From ages 12 to 18 children have a need to develop a sense of identity and social contribution. Children in this range benefit from research, critical thinking challenges, and the ability to apply knowledge to real-world scenarios. Successful learning models for this age group often enable active participation in activities rather than passive absorption of knowledge. Key learning objectives for this stage include personal ownership, responsibility, practical knowledge application, and academic autonomy as well as goals from previous stages at a higher level of complexity such as complex critical thinking, problem-solving, cognitive flexibility, and social skills (Murray, 2023).

2.2.3 Play Types and Types of Learning Experience

Understanding of different play types is essential when designing educational play experiences, because with different play types come different possibilities for learning. Many different models have been created in an attempt to organize and define different types of play. Each model for organizing play types is different in the way it organizes player activity, though many overlap with others. For brevity, some categories are left out of this study if they have enough of an overlap with a category analyzed in another model.

2.2.3.1 Two Types of Play by Experience Defined by the National Institute for Play

The National Institute for Play defines two separate types of play - free play and directed play. This method differs from other models as it is much more broad, but its broadness is actually to its benefit. Most other models for defining play types focus on very specific activities, but fail to consider the importance of self-direction when defining play. Instead of limiting play definition to a single model, using this model in tandem with others helps to build a better understanding of possibilities of play at all levels of player choice and action (National Institute For Play, 2023).

2.2.3.1.1 Free Play

Free play is defined as having five key characteristics as follows:

1: Free play is self-chosen, and self directed

2: Free play is intrinsically motivated

3: Free play is structured or ordered based on the rules in the player's mind

4: Free play is imaginative, or has creative aspects

5: Free play necessitates a playful state of mind by being very engaged, alert, mentally active, and focused, but not stressed about the activity (National Institute For Play, 2023).

With the exclusion of the fifth characteristic, this is a very useful way to categorize a type of play. These features suggest that free play encourages a high degree of self-motivated action that could lead to well-practiced adaptability, creativity, interest forming, and autonomy. The value free play brings simply from being recognized as a comparable option to others is great, as few other categories acknowledge the ability of a child to decide their own activities. Most treat play as a crafted experience, which is the most relevant to acting on childhood development, but ignores any potential value from giving a child choice. It also ignores the possibility of designing products to influence free play. For example, a sharp, dirty stick used in free play of a child may be visualized as a sword one moment and a gun the next, but if a product was designed to take the place of this stick while providing a safer experience and still allowing for full creativity, it would be influencing the child's play while maintaining free play. As the National Institute For Play (2023) notes, it would be considered a toy or decoration to enhance free play rather than a game.

2.2.3.1.2 Directed Play

Directed play is a much more straightforward type of play. It is simply play in which activities are directed, predetermined, restricted or influenced by some outside force, usually in the form of a set of rules. This is a much more traditionally accepted learning experience than free play and is much easier to use as a goal for product design. Benefits of directed play could include just about anything as it is such a broad category, but the creative and self-focused benefits offered by both free play and directed play are often better learned through free play. This may be due to the lack of freedom to act independently characteristic of directed play (National Institute For Play, 2023).

2.2.3.2 Six Types of Play by Need Defined by Montessori Education

Along with categorizing developmental age ranges, the Montessori education model is also known for categorizing types of play. These categories are named after the specific types of actions taken by players. Categorizing play this way has the benefit of giving observers the ability to infer what a player may be learning from their experience. However, designing products using this model as a guide to inform goals of player activity and early developmental stages is difficult. This is because most of these categories are based on general observations of players that are participating in free play or the lightly directed play of Montessori education. These types of play often fail to consider the player's interaction with physical objects and their environment. These activities are just as valuable as those categorized by Montessori play types. The following discussion explains the Montessori play types. Unless otherwise indicated, all explanations in this subsection come from Murray, A. K. (2023).

Unoccupied play is common in children from birth until they are about three months old. This type of play is defined and driven by the instinctual or impulsive desire of the player. Activities include thoughtlessly moving objects around, grabbing objects, feeling textures, and rocking. Benefits of unoccupied play include the development of motor skills and sensory development.

From birth until about two years old, children participate in solitary or independent play. This type of play is where personal interests, thoughts, and feelings are developed. Participants of solitary play often express a desire to act on their own without any outside guiding influence.

At around three years of age, children begin to observe the world around them. By watching, they learn about how things work outside of their own influence. This includes observations of themselves when looking into a mirror. Benefits of onlooker play include development of a sense of self, perspective, and development of observational skills.

Parallel play is very similar to solitary play, as it occurs from ages two to three and is defined by a desire to play by oneself. However, the difference comes in the inclusion of others. Parallel play may not often include a desire to share with others, but it does include a desire to play alongside others or watch others play.

From about ages three to four, associative play begins to be a focus for children. After developing a sense of self, children play with toys and use their imaginations. They create imaginative scenarios in an attempt to form interests and gain an understanding of different subjects and experiences that they have been exposed to.

Finally, cooperative play begins around ages four to six and is characterized by children working together to achieve some sort of common goal. This is one of the main ways children develop social skills and gain an understanding of the concept of rules (Montessori, 2022).

2.2.3.3 Piaget's Theory of Play

One of the earliest models for categorizing play comes from Swiss psychologist Jean Piaget. He breaks down play into four main types based on player activity. This goes beyond the Montessori categories by including player interaction with objects as one of the defining features of play. Unless otherwise indicated, all information in this subsection is drawn from McArdle, J (2021).

Functional play is defined by the player performing an enjoyable action, where the action itself is the focus and not much else. Put simply, this is the player finding pleasure through functioning and learning how to function. Functional play is most often seen in very young children that are still developing sensorimotor skills.

Constructive play gives players more agency over their actions, as it is defined by players manipulating something for the purpose of creation. This type of play assists in the development of creativity, independence, problem solving skills, and fine motor skills.

Fantasy play includes activities in which players act or replicate actions in order to gain a better understanding of the action they are participating in and create a stronger sense of preference and self. This type of play is a crucial part of early cognitive development and social skills as well as often being considered a prerequisite to literacy and numeracy.

Piaget's final category is known as games with rules, which is exactly as it appears. Play of this type includes games, usually with some metric of success, but always with rules. The most apparent benefit of games with rules is the development of self-regulation, as players must follow rules in order to participate. In addition to this, the challenge that comes from restrictions imposed by rules help to develop more advanced cognitive ability, social skills, and understanding of abstract concepts such as fairness (McArdle, J).

2.2.3.4 Simulations, Games, and Case Studies

In a study titled "Games and Simulations in Science Education", researchers analyzed different models of learning through play and created the following model:

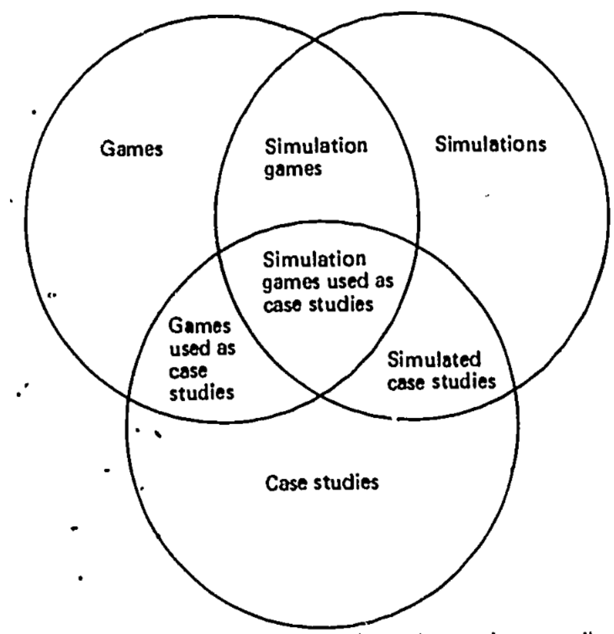

Figure 6: Model Relating Simulations, Games, and Case Studies (Ellington, 1981)

Here, learning methods are broken up into the main categories of games, simulations, and case studies with straightforward subcategories made from Venn diagram overlaps. Members of the subcategories are not much more than subjects that have the qualities of multiple main categories. Although relatively simple, this model of categorizing activities can be used to easily understand the possible benefits and direct the design of products simply by choosing or acknowledging the categories the products fall into.

This definition for games here aligns with Piaget's “games with rules”. Simply put, games are defined as activities that involve the restrictions of rules and some form of competition. This competition could be between players to achieve some degree of success or failure. This could either be through a quantifiable score of success or a qualifier of success, each of which could be used to determine success or failure alone or by being compared to those of other participants. Games in this sense bring value through increasing interest through fun and competition, though they are not inherently educational.

Simulations are defined as activities that represent the processes of real situations. This is said to exclude photographs, videos, and diagrams that may represent activities, as participants do not engage in the simulation of any process, even though they may view said processes. This category offers participants a chance to gain familiarity with both performing the simulated experience and memorization of contextual information.

Case studies are defined as “an in-depth examination of a real-life or simulated situation carried out in order to illustrate special and/or general characteristics”. The authors are very careful with this definition, as they specify that the defining feature of a case study must be the intent to study actionable information rather than including any sort of study of anything. This, like simulations, goes beyond simple memorization and instead allows participants to use information in specific ways or practice directed observation.

2.2.4 Existing STEAM Accreditation System

The Good Play Guide and The Toy Association have a program for accrediting toys and games as STEAM or STEM products. This is similar to what this study aims to accomplish and is a great step in the right direction for successfully designed STEM products. However, some of their accredited products do not have clearly understandable STEM benefits and contradict not only the definition of a STEM product as defined here, but also the attributes of STEM as defined by their own toy assessment framework model. In their framework, there are three categories they weigh to rate toys and games for accreditation (Gummer, 2023).

2.2.4.1 "Good Toy Characteristics"

The characteristics of a good toy makes up the first of the three categories. For a toy to be successful, it is rated as poor, good, or excellent in the sub-categories of being fun and engaging, easy to use, supporting skill development, and inclusive. This is also referred to as a toy's play value. While not directly related to STEM, the ability of a toy or game to retain a user's attention is very important and arguably a prerequisite for a product to be effective at helping the user understand and retain knowledge. For a toy to be deemed successful in this category, it must be rated as good or excellent in all three sub-categories (Gummer, 2023).

2.2.4.2 Prime STEAM Attributes

The next category is known as prime STEAM attributes. This is also broken into different sub-categories that are rated as poor, good, and excellent. These six sub-categories are real world relevance, active involvement, arts, logical thinking, free exploration, and supporting step-by-step learning.

Real world relevance closely aligns with the requirements for defining STEM earlier, as it demands "hands-on observation and use" (p.10) as well as a "clear relevance and application to the real world" (p.10). However, the example activities referenced by this category are fairly ambiguous. They are listed as "seeing real working mechanics, using measurements, or using scientific tools" (p.10). Broadly defining activities are typically helpful for including a wide range of products to be accredited, but these activities are broad in a similar way to how the term STEM is used broadly; they run the risk of including too many subjects. For example, being able to see working mechanics could potentially include anything with a gear, joint, lever, etc. Also, "using scientific tools" (p.10) is not clear about what does and does not qualify as a tool, bringing up the same issue as before, where something would be considered a scientific tool as long as it looks or feels science-like.

Active involvement refers to the ability of a toy to let children explore and interact independently by physically manipulating different parts or materials to understand problems and devise solutions. This is a very interesting requirement because independent interaction and exploration is very beneficial to a child's development, but requiring this as a defining feature rather than an approach is limiting.

Arts as a category is fairly self-explanatory and, as mentioned earlier, ambiguous. An excellent rating for art is described as follows:

> Actively encourages children to tap into their creative and imaginative skills to support divergent thinking. Children have the chance to use both the left (logical) and right (creative) sides of their brain. For example, expressing themselves through the arts such as design, drama (including role play), dance, music, history, or language.

The strongest defining feature of this is the combined use of creativity and logic. Necessitating both on one toy or activity helps to show the benefit art can bring to childhood development. However, the next section is much more vague, allowing for most expressive activities to qualify as art. This vagueness is what makes art such a difficult subject to define. While it would be helpful to define art as requiring specific features such as logical thought, it seems necessary to include traditional artistic activities that do not always require logical thought such as visual arts, dance, and music. The combination of the two as described is more reminiscent of design.

An excellent rating for logical thinking is described as independent problem solving through trial and error, investigative learning, and logic principles. These are all beneficial learning outcomes that align with educational goals for STEM learning.

Free exploration is the next listed STEAM quality. It is described as the freedom to repeatedly explore one's own ideas. Most other qualities also mention independence in their description, so free exploration as its own category seems unnecessary. However, it is possible that the author intended for this category to make sure that qualified products are not simply lessons with no room for experimentation and varied results. Instead, qualified products should be open-ended even if there are generalized instructions.

The final qualifier of STEAM product accreditation is step-by-step learning. An excellent rating of this is described as follows:

> Includes additional guidance for adults, which can help them support the child's learning to extend their knowledge past their comfort zone. Activities included with the toy offer different levels of challenge, gradually increasing in difficulty, which may help children grow their confidence.

This leans more in the direction of programming through instructions rather than open-ended play possibilities. It also focuses on adults assisting and guiding children through play.

This focus on requiring some level of planned activity, especially those at a higher than usual level of cognitive function, encourages a certain level of quality in products that otherwise may be used a very limited number of times.

2.2.4.3 Specific STEM Categories

The last of the three categories used for accreditation is specific STEM categories. Unlike the other categories, this section does not use any sort of rating system and instead requires a product to support "one or more learning goals in at least two STEM subjects". Subjects, in this case, refer to different focus areas related to science, technology, engineering, and mathematics. The learning goals for these subjects are divided into different age groups in order to associate them with assessed products of a similar demographic. The age ranges listed are 2 to 3, 4 to 6, 7 to 9, 10 to 12, and 12 and up, which is similar to, but more specific than the Montessori age groups. This is because the learning outcomes are largely based on the Next Generation Science Standards, Society for Technology in Education standard, and the Common Core States Standards Initiative for different school grades.

The structure of this system is mostly well organized. The organization of learning outcomes assists in the appropriate design of products. However, there are problems in the details of this section. Just like with the ambiguity of the term STEM from earlier, the STEM categories here are used superficially and seem to rely on being classified as STEM because the content evokes a feeling of STEM. For example, "observing weather patterns" (p.17) is listed as a science learning outcome for ages 4 to 6 and "using basic devices and software applications" (p.22) is listed as a technology learning outcome of ages 7 to 9. These seem like science and technology-related activities but have no measurable metric of success. Because this section lacks any measurable rating system such as the ones from the previous two categories, all of the learning outcomes are recommendations of possible activities rather than something that provides a measurable benefit for the user.

There is also a separate issue that is mostly present in the younger age groups of this category. Many of the learning outcomes are not related to STEM at all but act more closely to prerequisite skills that enable future learning that may or may not be related to STEM. For example, “object permanence” (p.13) is listed as an engineering outcome for ages 2 to 3 and “planning and investigating with guidance” (p.16) is listed as a science learning outcome for ages 4 to 6. These are very basic skills that have no inherent real-world application - something that is even required by the previous STEAM section. As stated before, without real-world application, prerequisite skills such as these cannot be considered STEM with no applied context.

2.2.4.4 Accredited Product Examples

The final and possibly largest issue comes from the linked amazon page of accredited products. While the accreditation program is well structured with a few inconsistencies, some of the accredited toys seem to not have the qualities required to qualify. Instead of listing the educational benefits used to gain accreditation, these products only show the STEAM Accredited Toy label. This shows just how hard it is for consumers to accurately understand the value of items being advertised as STEM products, leaving them to assume the toy’s educational value, if any.

Figure 7: Snap Circuits Electronics Exploration Kit (Amazon.com, 2025)

The Snap Circuits Electronics Exploration kit is a well-known STEM toy that appropriately qualifies for each category of the Toy Association Accreditation System. Designed for children at least 8 years old, the kit lets children explore how electricity works in different ways and at their own pace, but with the optional assistance of a project manual for guidance. This puts the real-world application of circuits on full display, allowing for a better understanding of future learning and application of knowledge through experience. This toy can be easily related to the topics of science, technology, engineering, and mathematics, far exceeding the minimum requirements of the framework. The packaging of this toy prominently lists STEM as a benefit but does not use the accreditation label.

Figure 8: Weplay Jumbo Circus (Amazon.com, 2025)

The Weplay Jumbo Circus is a set of building blocks that is designed in a way to encourage experimentation with balance, ramps, wheels, and creative configurations. While not as straightforward as a learning tool as Snap Circuits, this toy puts on display the relationship between multiple physical properties like mass, weight distribution, and velocity through parts that can be reconfigured for comparable experiments. While a child might not be able to articulate the reasons for the results of changes in configurations, they can easily observe how the parts interact with each other. Because the interaction of physical properties is applicable to real world scenarios, the toy can still be justified to have a real-world application despite its lack of specific theme or context. Despite its educational benefits, the term STEM is entirely absent from this product's packaging and product description.

Figure 9: LEGO City Lunar Space Station (Amazon.com, 2025)

The LEGO City Lunar Space Station is hard to define as STEM, STEAM, or neither. LEGO in general is well known for its ability to assist childhood development through play similarly to Montessori toys, but simply linking together blocks is not necessarily applicable to any real-world context without some specific STEM learning outcome on display. Instead of learning through complex systems that are a part of LEGO robotics kits, this one seems to only be themed around space as a STEM-related subject. While the parts can be rearranged to fit any configuration, this modularity has no inherent educational direction like the Weplay Jumbo Circus has with balance, mass, and momentum. Because of this, it should fail to meet the criteria set by the second section of the accreditation framework that requires real-world relevance, as well as the third section that requires one or more age-appropriate learning goals. The term STEM is entirely absent from this product's packaging and product description.

Figure 10: Pix Brix Pixel Art Puzzle Bricks (Amazon.com, 2025)

Pix Brix Pixel Art Puzzle Bricks are essentially a different version of LEGO building blocks. They allow for two- or three-dimensional compositions of blocks in different colors. The reasons this product should not qualify as a STEAM toy are the same as the previous LEGO set as it lacks any real-world relevance. Additionally, there is no STEAM-related theme present and because all of the blocks are the same shape, there is little room for creativity in configurations that are not solely dependent on color. Furthermore, there is no connection to at least two STEM subjects or even a learning outcome associated with one. This product's packaging describes the product as STEAM, and it has won the 2021 Newsweek Best in STEM award.

Figure 11: Special Supplies Stepping Stones (Special, 2025)

Special Supplies Stepping Stones are a set of rubber stepping stones that promote childhood development of balance. Other than this developmental benefit and the claim of sensory play through the use of color, there are no other developmental or educational benefits listed on this product's page. While it meets the criteria for being a good toy as defined by the first section of the framework, the only criteria it meets in the next two sections are "free exploration" (p.11), and "active involvement" (p.10). Notably, this is the only product of these six listed that uses the STEAM accreditation label and costs around 20 dollars more than other products of the exact same shape.

Figure 12: Strider Balance Bike (Amazon.com, 2025)

Strider balance bikes are essentially bicycles with optional pedals. The intention with these products is to help children develop a sense of balance by stepping on the ground rather than pedaling and occasionally lifting up their feet. By the logic used to define these bicycles as a STEAM toy, either every bicycle should be considered a STEAM toy or only stripped-down bicycles should be. There could be an argument made for bicycles to be products that put physics on display or visible mechanics of technology and engineering, but the same could be said about any object in motion or device with visible moving parts and a line must be drawn somewhere. Just as with the Weplay Jumbo Circus and the space-themed LEGO set, this product appears on the list of STEAM products, but the terms STEM or STEAM are entirely absent from the product's own page.

When compared against each other, each of these accredited product examples puts on display the inconsistency of what defines a STEM product and highlights a need for the creation of a definition that can be used in product design to inform the design of consistent and effective STEM products. The previous definition for the term STEM product is used in the following guidelines and is as follows:

STEM Products - Products that, through use, demonstrate applied knowledge within at least one of the fields of science, technology, engineering, or mathematics

Chapter 3 STEM Play Product Design Guidelines

3.1 Overview of Design Process

Using the information gathered above, the guidelines below aim to assist designers in structuring the design process of educational products that appropriately qualify them as STEM products. The process consists of four stages, the first three of which are divided into three categories based on educational goals, target user demographics, and product specifications. Decisions in each step of the process inform decisions in each subsequent step, further refining design decisions to more accurately achieve the goals that align with designers' intentions.

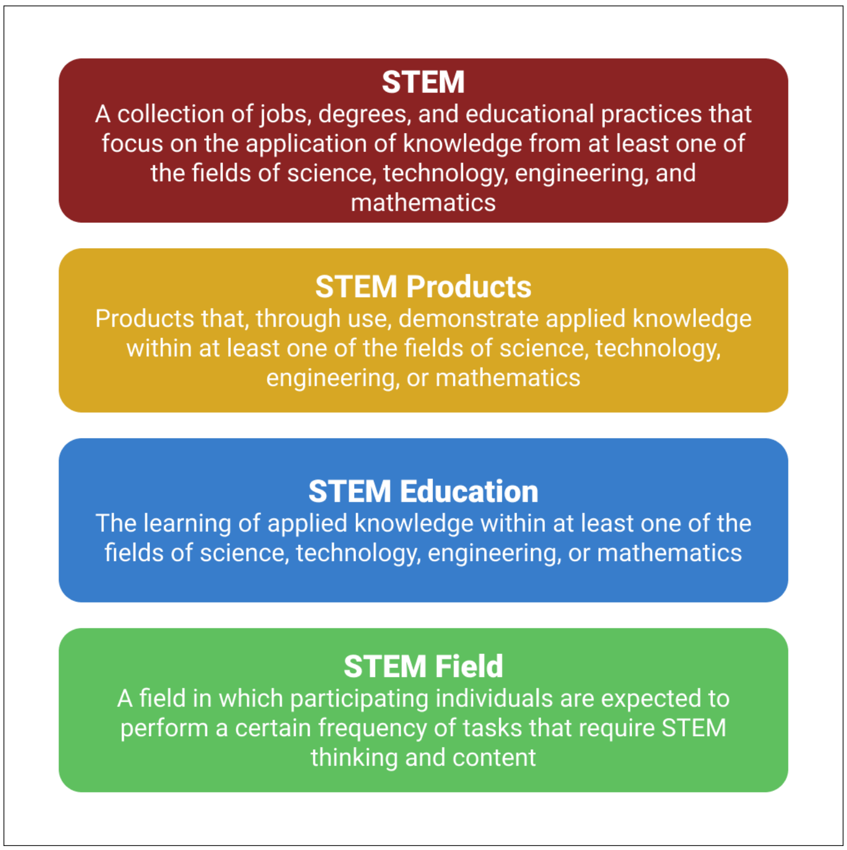

Figure 13: Definitions used in STEM Product Guidelines

The following diagram is a visualization of the guidelines, dividing each step of the process and combining information of categories from each step into the categories of subsequent steps.

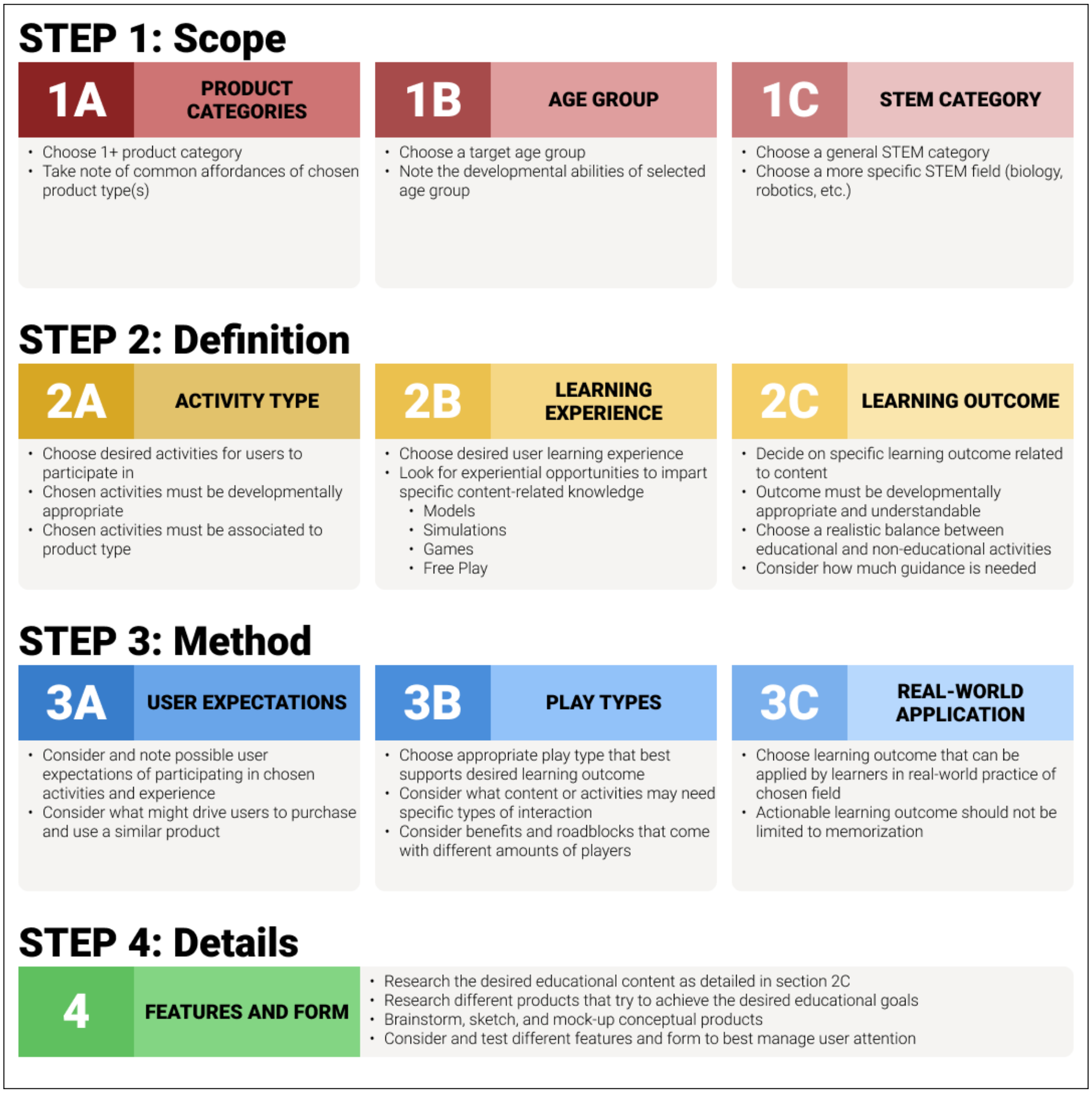

Figure 14: STEM Product Process Diagram with Instructions

In order to use this process effectively, it is important for designers to understand the goals for their project. Some sections of this process may be detailed beforehand in a design brief in which case the designer may either use the diagram as a map to guide the rest of their decisions to create a more effective product or as a way to highlight weaknesses and contradictions in the design brief itself. For example, if a brief has the goal of creating a toy that teaches high-level rocket science to children ages 2 to 4, designers can visually show on the diagram how the educational goals of the product do not align with the age range of the target users. Because of this, the diagram may also be used to structure design briefs to have easily understood design goals with an easily adjustable amount of flexibility.

Sometimes, earlier steps may be loosely defined or entirely undefined although later steps are well defined. In this case, designers can use the process backwards to fill in the previous categories most appropriately. For example, a project brief may task designers to design a product that teaches coding (3C) and has some element of discovery and creation (3A). Using this information that would be in sections 3A and 3C, section 2B may be filled out as or changed into a model as the intended content-related learning experience. To clarify, defining the product as a model is not the only solution, but models do often have qualities that tend to effectively impart the type of knowledge upon users through the activities required by the brief.

Occasionally, some of the categories may be in conflict with one another. If this is the case, designers should look for related sections that may be altered to inform and justify the design of a product more cohesively. Below is a diagram showing how sections are most likely to relate to other sections. By referencing this, designers can check for discrepancies between linked sections and adjust accordingly. This may also be used to more accurately critique the design of existing products and justify why or why not the subject is a successful product.

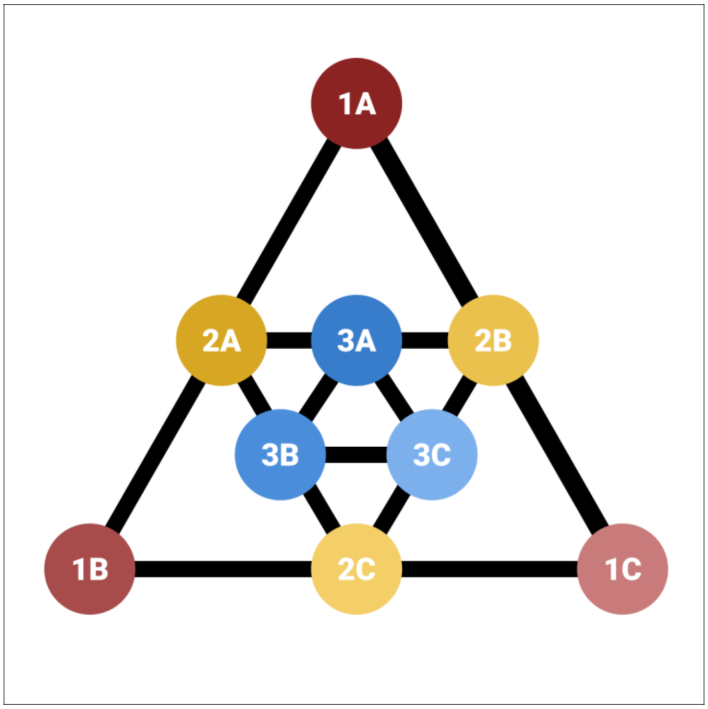

Figure 15: STEM Product Conflict Diagram

3.2 Step One - Scope

The first and most general stage of the design process is to define the scope of the project. In this stage, only the most general information is gathered for what is being designed and who it is being designed for. This includes the product type, age group, and general STEM category.

3.2.1 Section 1A - Product Categories

When defining the type of product, designers may have some idea of what they want their product to do, but not know exactly what they want it to be. If this is the case, briefly jumping ahead to section 2A and 2C may help guide the decision of what the desired product might be. There may be multiple product categories decided upon here, each with their own opportunities and restrictions. The following table organizes examples of different product categories and how they may inform future steps. This is not a comprehensive list, but it gives common examples of general product types.

Table 1: Section 1A – Common Product Category Examples Reference

SECTION 1A PRODUCT CATEGORY	COMMONLY ASSOCIATED ACTIVITIES	COMMONLY ASSOCIATED LEARNING EXPERIENCE
Dolls, plush toys, and action figures	Role Play	Simulations, Free Play
Miniatures	Role Play	Models, Free Play
Role-play tools	Role Play	Simulations, Free Play
Costumes	Role Play, Physical Activity	Simulations, Free Play
Rideable toys	Role Play, Physical Activity	Free Play
Interactive stories	Reading, Role Play	Simulations
Sensory toys	Observation	Models
Activity centers	Observation, Physical Activity	Simulations, Free Play
Learning aids	Observation	Simulations, Free Play
Building blocks	Construction	Free Play
Arts and craft kits	Construction, Model Making	Models, Free Play
Modeling material	Construction, Model Making	Models, Free Play
Model kits	Construction, Model Making, Role Play	Models
Playsets	Role play, Model Making, Searching/Finding	Simulations, Free Play
Science kits	Construction, Observation, Analysis, Model Making, Trial/Error, Role Play	Models, Simulations
Construction puzzles	Construction, Observation, Analysis, Trial/Error	Models, Games
Information puzzles	Observation, Analysis, Comparing/Contrasting, Answering Questions, Reading, Writing	Games
Interactive puzzles	Construction, Observation, Analysis, Comparing/Contrasting, Trial/Error, Searching/Finding	Games
Programmable toys	Observation, Analysis, Trial/Error	Models
Board games	Analysis, Trial/Error, Answering Questions, Reading	Games
Card games	Analysis, Trial/Error, Answering Questions, Reading	Games
Playground equipment	Physical Activity	Free Play
Sports and active gear	Physical Activity	Free Play

To complete step 1A, designers must describe the intent for what they wish their product to be to the best of their ability. At this stage, only general product types should be considered in order to not create too specific of a project direction. A product may be defined as multiple product categories. If this is the case, designers should look for shared opportunities for learning experience and activities afforded by each.

If section 1A is filled out by a designer, the selected product categories should reflect the initial, general intent of the designer, which may be altered once later steps are completed and the project becomes more refined. However, if section 1A is already filled out in a design brief, designers may not have the agency to stray from this chosen direction.

3.2.2 Section 1B - Age Range

Many design projects define target users using age as a key demographic. This is especially important when designing educational products, as different age ranges tend to have different levels of ability to understand presented content and learning methods. If not already defined in a project brief, section 1B requires designers to decide on a target user age range so that appropriate activities and learning outcomes may be detailed in future steps. Below is a list of suggested age ranges and learning capabilities of each. Although different age range models may be referenced here, these guidelines suggest using Montessori age ranges to define developmental capabilities and learning methods. Additionally, these guidelines suggest using a combination of the Next Generation Science Standards, Society for Technology in Education standard, and the Common Core States Standards for defining appropriate content for the target age group or groups. If specific educational goals or activities have been decided on before this step, an age range that can understand the decided content and participate in the decided activities should be defined. Below is a table of different age ranges and examples of developmental milestones of each.

Table 2: Section 1B – Age Range Reference Information

SECTION 1B AGE RANGE	DEVELOPMENTAL MILESTONES
Ages 6-8	Problem Solving, Identity Autonomy, Cooperative Play
Ages 9-12	Abstract Thought, Emotional Regulation, Academic Autonomy
Ages 13-18	Independent Thought, Social Awareness, Goal-based Learning

3.2.3 Section 1C - STEM Category

In the final section of preliminary information, designers are tasked with deciding on a general STEM category. This may be as general as a STEM category (science, technology, engineering, or mathematics), but may also be as specific as a STEM field (biology, microbiology, robotics, physics, algebra, trigonometry, etc.). No matter what branch of STEM is decided upon, this section should be no more than a category and should not yet reflect any specific learning outcome. Along with helping to justify the end product as a STEM product, the content of section 1C helps designers to decide on appropriate related learning outcomes as well as appropriate learning methods in future steps. Below is a table of examples of stem categories and related subcategories that designers. As there are many subjects that may be defined as STEM, this is by no means a comprehensive list. It is the role of the designer to come up with their own category or categories as well as identifying specific learning objectives.

Table 3: Section 1C – Common STEM Category Examples Reference

SECTION 1C STEM CATEGORIES	POSSIBLE EDUCATIONAL FOCUS
Biology	Biological processes (Metamorphosis, Organ systems, etc.)
Microbiology	Bacteria, Cells
Chemistry	Chemicals, Reactions
Astronomy	Celestial bodies, Orbits
Medicine	Hospital practices, Diagnosis, Treatment
Digital Technology	Logic, Programming, Circuits, Electricity
Robotics	Programming, Sensors
Architecture	Materials, Weight, Construction
Simple Machines	Work, Physical forces (Weight, Momentum, etc.)
Physics	Fundamental laws of physics
Algebra	Equations, Variables

3.3 Step Two - Definition

Once the scope of the project is decided upon, it should be further defined in step two. This step tasks designers to combine the desired product type or types, demographic information, and general educational goals into three categories that detail specific educational and product use goals. In section three, these goals will direct designers in deciding on and creating a method or methods of how to achieve them.

3.3.1 Section 2A - Developmentally Appropriate Activity Types

By considering the opportunities and limitations of the chosen age range of section 1B and the chosen product types of section 1A, designers can choose appropriate activities that users might engage in when using the designed product. Simply put, this category reflects what designers intend for users to do while using their product. Age ranges mostly act to detail the physical and developmental limitations of users as well as highlight opportunities to select activities that may be particularly effective for the chosen demographic. Similarly, different types of products have different limitations of what activities they can be used in and what activities they are especially effective at supporting. The table below is a list of different example activities and their opportunities for enabling different user actions that designers may wish to employ.

Table 4: Section 2A – Common Activity Type Examples Reference

SECTION 2A EXAMPLE ACTIVITY TYPES	ASSOCIATED LEARNING OPPORTUNITY
Construction	Familiarity with manipulated parts/processes
Observation	Familiarity with observed content
Analysis	Critical thought and familiarity with content
Trial and Error	Critical thought and familiarity with content
Searching and Finding	Critical thought and familiarity with content
Comparing and Contrasting	Critical thought and autonomy
Answering Questions	Critical thought and autonomy
Writing	Autonomy and familiarity with content
Reading	Autonomy and familiarity with content
Role Play	Familiarity with content/processes and autonomy
Model Making	Familiarity with manipulated parts/content/processes
Physical Activity	Autonomy

These actions are relatively general as there are likely no detailed components or structured activity at this point in the process. Examples of this section include activities like construction, trial-and-error, and investigation, all of which may either be chosen beforehand or drawn from the overlaps of the categories detailed in sections 1A and 1B. Conflicts between section 2A and its prerequisites are suggested to be resolved in the three following methods:

Option 1 - conflicts may be resolved by choosing different product categories in section 1A and/or a different age range in section 1B to more closely match these parameters to the chosen activity types.

Option 2 - conflicts may be resolved by choosing more appropriate activity types that have more of an overlap between the previous sections.

Option 3 - conflicts may be used to prompt designers to create unique solutions in order to address or resolve them.

For example, in the case of an age-activity conflict, a discrepancy is created by chosen activities (Analysis) being too complex for a chosen age group (Ages 3-6). By choosing option 1, designers may choose to prioritize maintaining the activity of analysis and broaden their previously defined age range. By choosing option 2, the activity of analysis may be dropped in favor of observation or manipulation, as these are more age-appropriate activities. By choosing option 3, designers may choose to justify choosing analysis as an activity by clarifying it as an opportunity for higher-level learning. Analysis would then become a secondary activity while a new, more age-appropriate primary activity should be chosen such as construction or observation.

As another example, in the case of a product-activity conflict, a discrepancy is created by chosen activities (Construction) not aligning with the typical or inherent features of a chosen product type (Dolls). By choosing option 1, a different product type such as building blocks may be considered if designers prioritize maintaining analysis as the primary activity. By choosing option 2, designers may prioritize maintaining the objective of designing a doll and select a different activity type more appropriate to dolls. By choosing option 3, designers may use the discrepancy as an additional design goal to be met later. This may happen in step 4 - features and form - where unique features may be designed that result in a doll that allows users to participate in construction, such as one that requires users to build it from scratch or one that is used as a construction tool itself in some way.

3.3.2 Section 2B - Content Driven Learning Experience

Different product types lend themselves more easily to different learning experiences. Similarly, different content may be better suited to be learned through one type of learning experience rather than others. Section 2B tasks designers to choose a type of learning experience based on their previously chosen product types in section 1A and the educational content they wish to impart on users.

In this section, learning experiences are divided into the following four types: models, simulations, games, and free play. Definitions of models, simulations, and games are categories drawn from "Games and Simulations in Science Education" while the definition for free play is drawn from the National Institute for Play. The category of models here is used in place of case studies as defined in "Games and Simulations in Science Education" for clarity and relevancy to product design. Simply put, this category reflects how designers intend for users to learn while using their product. Below is a reference table of learning experience types and what each excels at.

Table 5: Section 2B – Learning Experience Reference Information

SECTION 2B LEARNING EXPERIENCE TYPE	POTENTIAL EDUCATIONAL BENEFITS	POTENTIAL EDUCATIONAL HURDLES
Models	Observable features of content, Measurable features	Lack of context, Lack of understanding relevance of content
Simulations	Observable features of content, Experiential actions within content, Unique personal experience	Limited opportunity for free exploration, Lack of understanding purpose of actions
Games	High engagement, unique personal experience, inherent metric of success	Limited depth of learning, Inter-player conflict
Free Play	Free exploration, Unique personal connection	Lack of educational structure, Hard to measure metric of success, No inherent engagement

This table does not act as a strict set of rules for how certain content must be learned and what the only activities certain product types can be used in are. Instead, this table is meant to guide designers by highlighting opportunities in learning experience that they may not realize on their own. As step 2 of the guideline chart is the definition, completion of step 2B simply acts to give designers a more clearly defined project direction than would be found in step 1 alone. As such, there should not be any conflicts in this step between learning experience and product type or content. Instead, this section should only highlight issues in the product design if the learning experience goal is not met by the associated sections in step 3.

3.3.3 Section 2C - Developmentally Appropriate Learning Outcomes

As people in different age ranges have different levels of ability in terms of understanding learned content, specific learning outcomes should be defined so that designers have a more specific goal to aim for in terms of what they want users to be able to do or understand after using their product. This is done by first acknowledging the limitations of the chosen age range in section 1B and choosing an appropriate learning outcome that relates to the subject matter chosen in section 1C. The following table details different age ranges and developmentally appropriate learning outcomes that are not related to a specific STEM subject.

Table 6: Section 2C – Example Learning Outcome Reference

SECTION 2C EXAMPLE LEARNING OUTCOMES	TARGET AGE RANGE
Identify key features of content	Ages 6-8
Identify relationships between key features of content	Ages 6-8
Use basic tools to observe and solve problems with little need for assistance	Ages 6-8
Record and compare measurements	Ages 6-8
Quantify simple data	Ages 6-8
Perform simple calculations	Ages 6-8
Identify and make comparisons of specific details	Ages 9-12
Perform variable tests and record results	Ages 9-12
Understand abstract concepts and apply/relate them to content	Ages 9-12
Understand the relation and interactions between different parts of a system	Ages 9-12
Perform actions within a given task independently or with little assistance	Ages 9-12
Collect, record, and organize data in charts and graphs	Ages 9-12
Apply learned knowledge to multiple disciplines	Ages 13-18
Identify and predict tendencies within a system	Ages 13-18
Perform complex calculations	Ages 13-18
Design solutions to complex problems with open-ended solutions	Ages 13-18
Critically analyze the inter-related parts of complex subjects	Ages 13-18
Perform open-ended tasks independently and efficiently	Ages 13-18

Defining this section, much like section 2B, acts as a goal for designers to meet in later steps. After completion of the entire design process, this section also helps to justify products as STEM by presenting a specific goal rather than a general STEM topic.

3.4 Step Three - Method

After detailing what their product will be in step 1 and detailing what their product will do educationally in step 2, the designer should have a clear project direction and can begin detailing what their product must have to achieve those goals in step 3. This is done by deciding how the designer expects users to be invested in their product, how much educational value the designer expects their product to have, and how the product's educational content can be applied to the real world. This is the final step of defining project goals and at this point in the process, designers should have a relatively clear vision of what their product is, what features it will have, and what it might look like to better achieve their goals. These features may inform how to market their product through key selling points of the product beyond simply what the product is and can help designers, consumers, educators, and users alike understand its educational benefits and use cases.

3.4.1 Section 3A - User Expectations

Once the activity types of section 2A and learning experience of section 2B have been defined, designers should decide what they would like and expect users to want out of the product and why they are invested in initial purchase and recurring use. For example, in this step a designer asks themself, "What could be someone's goal for participating in construction within a game?" for which answers may be to create something personal and unique, to compete against others or themself in trying to make something as accurate to a set goal as possible, or some combination of the two. As another example, a designer may ask themself, "What would someone want to get out of a simulation that encourages trial-and-error?" for which an answer may be to discover the most optimal operating procedure for a desired outcome, to explore creative and unusual methods of completing a task, or to discover their own favorite method of achieving a particular goal.

In this section, design decisions are much more free form than in previous sections, but contradictions may still arise. If the designer cannot think of a reason for users to want to interact with their product based on the choices made in sections 2A and 2B, it is suggested that they try other options for those sections that more closely align with each other. Below is a list of different combinations of activity type and learning experience and how they might be combined to inform expectations of user goals.

Table 7: Section 3A – Example User Expectation Reference

SECTION 3A EXAMPLE USER EXPECTATIONS	EXAMPLE ACTIVITY TYPE	EXAMPLE LEARNING EXPERIENCE
Construction puzzle elements, Varied results, Some metric of success	Construction, Trial and Error	Model
Recording data results from activity, Deeper understanding of content complexity, Familiarity with processes to achieve a desired result	Observation, Analysis, Answering questions	Simulation
Feature recognition required, Possibly speed as a game element, Critical thought required when comparing found elements, Experience varies with situational elements	Searching and Finding, Comparing and Contrasting	Game
Written puzzle elements, Critical analysis of text, Reading comprehension required	Reading, Writing, Analysis	Game

Once this section is detailed, designers can justify their design as something that would interest a particular target audience with specific interests, which may be used as a selling point to advertise to consumers of that particular demographic. It is recommended that such selling points should not be related to too much specific educational content and instead highlight the actions afforded to the user. For example, a product may be advertised as being fun for those who like to explore and create a 3D puzzle model of a cell, or as being fun for those who want to see if they can design a circuit board within a game using randomly chosen parts. These examples focus more on the actions of the user rather than the specific content-related learning outcomes, which is decided in other steps.

Throughout this entire process, it is important for designers to keep in mind that along with the educational value of the product they are designing, there should also be some amount of fun that motivates the user. After all, this process is meant to be used for designing toys and games. That being said, just as people of different age groups have different abilities to learn a particular amount or type of content (as discussed in section 2C), people of different age groups are also motivated by and able to participate in different activities (as discussed in section 2A).

In section 3A, a balance between fun and strict educational value must be decided upon that is both appropriate to the target age group and realistic considering the previously chosen activity types. While both fun and educational value may be used as selling points, a designer may wish to prioritize fun to increase expected user interest or prioritize educational value to improve the expected learning outcome and have more focus on this as a selling point. For this section, there are no best answers and designers are encouraged to use the result of this section as a goal for how much of each attribute should be given attention through form in step 4 and how much activity needs to be encouraged that is educationally productive. It is encouraged for designers to write down the relative amount of fun and learning they intend to be the focus of their product as well as their reasoning for choosing this ratio. Examples of the completion of this step may look like any of the following options:

- In order to maintain the attention of users ages 3-6, this product is intended to be more fun than educational.
- Assuming users, ages 12-18, have the intention to learn on their own or are given this product as a supplemental learning tool, this product is intended to be more educational than fun.
- In order to have the most shelf-appeal to a wide range of consumers, both fun and educational value are given equal weight.

It should be noted that even if a product is decided to have more of a focus on fun than educational value, it is still required by other steps of these guidelines to have a certain level of specific educational value to be considered a STEM product.

3.4.2 Section 3B - Play Types

In order to best facilitate learning for users of the target age group of section 1B, through the desired learning experience of 2B, and utilizing the activity type chosen in 2A, designers are tasked with choosing an appropriate play type. Play types are most commonly associated with how different age groups learn through play. However, play types that are most present in an early developmental stage are still present in later stages and are potentially more effective in imparting knowledge for different types of subject matter. The table below lists different play types along with different unique benefits of each. Designers should select one or more of these play types that best suit the goals detailing in previous categories.

Table 8: Section 3B – Play Type Reference Information

SECTION 3B PLAY TYPE REFERENCE	EDUCATIONAL BENEFITS
Unoccupied Play	Sensory experiences
Solitary Play	Personal taste development, Free exploration of surface-level content
Onlooker	Observation-focused
Parallel Play	Shared experience, Comparison to others' actions
Associative Play	Association between content and actions
Cooperative Play	Discussion, Teamwork skills
Constructive Play	Creativity, Dexterity, Observation of parts
Fantasy Play	Imagination, Personal connection to content
Free Play	Autonomy, Personal connection to content, Player learns at their own pace

3.4.3 Section 3C - Understanding of Real-World Application

In order to address the discrepancy of educational products sometimes being mislabeled as STEM when they only offer developmental benefits and appropriately design products in accordance with the definition of STEM detailed in chapter 2, it is required by section 3C for a product to be able to incorporate real-world application of learned educational content outside the context of the toy or game itself. To achieve this, a product must go beyond simply imparting memorized knowledge and instead give an example of use in context within a STEM field either through repeatable practiced actions detailed in section 2B, through description and demonstration of the learned content of section 2C in a real-world context, or both.

This understanding of real-world content might not be the main focus of the product, but it must be able to be reasonably understood by the intended target users. To ensure this, designers must draw at least some attention to both the result of this section either through the form of the product in step 4, or through the rules or instructions of use in the case of a product that can be used multiple ways, not all of which impart contextual knowledge. In this case, the product's rules or instructions must be made readily available and apparent to the user.

3.5 Step Four - Features and Form

The final step of the design process is simply to decide on what features a product should have and what it should look like to best achieve the goals detailed in the previous sections. This could mean adding parts and visual features to draw attention to a particular aspect of the product such as distinct interactable parts of a model. It could also come in the form of including play-tools that simulate the experience of practicing within a STEM field. There is no comprehensive list of what can or cannot be included here, but as stated in section 3C, the real-world educational value of the product must be apparent and able to be understood by the intended target user. Depending on the personal standard operating procedures of the designer or their company, the designer may choose a different design process to continue or finish developing their product. The example below is a recommended generalized process for how to design a product concept that meets the goals set in steps 1 to 3. By answering the questions and tasks below, designers should be able to better visualize a concept for a STEM product that they can later design for production.

- Research the desired educational content as detailed in section 2C.
    - What are common activities taken within the chosen STEM field?
    - What knowledge is required for one to operate in this field?
    - What, of this knowledge, can be reasonably understood by the target user?
- Research different products that try to achieve the desired educational goals.
    - What approach do these products take to impart knowledge as would be detailed in sections 2A, 2B, 3A, and 3B?

    - What are the benefits of presenting knowledge this way?
    - What are the shortcomings of presenting knowledge this way?
    - Can any part of the educational approach used in researched products be replicated for this product?
- Brainstorm, sketch, and mock-up conceptual products of the chosen product type of section 1A that incorporate as many features detailed in later steps as possible.
    - What features does the product need to have to operate?
    - What features are needed or can be added to improve the quality of the user's educational experience?
    - How open-ended should the use of this product be?
    - What key features should be highlighted to direct the user's attention?
    - How might the product change to visually direct the user's attention?
    - How might the product change to physically direct the user's attention and limit misdirected use?

No matter what approach designers use to create product concepts, it is recommended that they end their process by considering how the product might best be altered physically and visually to direct the user's attention and limit misdirected use. The purpose of doing this is to give greater emphasis on the educational content presented by the product and improve positive learning outcomes through use.

3.6 Product Evaluation and Alteration

After the initial design process has been completed, the conceptual product can be checked by the designer by employing steps 1, 2, and 3 as standards for the product to meet. If a conceptual product fails to meet any of the design criteria and educational goals decided upon in these steps, designers should decide to either make alterations to their product to better meet these goals or, if possible, narrow the scope of the goals to be more realistic while still maintaining a positive STEM educational outcome. Regardless, designers should repeat the evaluation and alteration process until they have a product that appropriately aligns with their chosen design criteria.

In much the same way as the process diagram can be used to evaluate and alter conceptual products that have gone through this design process, it can also be used to evaluate existing products in two ways. First, products can be evaluated on whether or not they appropriately qualify as STEM products by deciding whether or not their relation to sections 2C and 3C can be defined. Second, products can be evaluated on how successful of a product they are and how successful of an educational experience they offer by filling out how it relates to each section. Afterwards, any inconsistencies or conflicts within sections might highlight potential design flaws while clearer connections between sections can be used as justification for calling the products successful.

Chapter 4 Example of Guidelines in Use

In order to better demonstrate the set of guidelines proposed in chapter three, this section provides a simulation of the guidelines in use. This example goes through all the steps of the guidelines and gives reasons for choices made within each step. Designers are recommended to reference this section if any confusion arises during their design process and further assistance is required to complete their own design.

4.1 Step One - Scope

Without any idea for a specific product in mind, but with the task of designing a STEM product, the first step is to detail the broad scope of the product. This will include the initial ideas for product categories, target age range of users, and broad STEM category.

4.1.1 Section 1A - Product Categories

To start with, the following product categories will be chosen:

- Doll, Plush toy, or Action Figure
- Construction Puzzle
- Information Puzzle
- Board Game
- Card Game

These categories may be chosen randomly but are best chosen by the designer if they can visualize users learning through while using a product of that type. In this example, the designer may choose each of these categories not because of the opportunity to combine them, but because it may be what they are most familiar with designing or even because of a personal desire to attempt designing an educational product of one particular category. It is important to note that these are simply initial categories and the contents of section 1A may be added to or narrowed down later.

4.1.2 Section 1B - Age Range

As with each other section, unless a project brief has previously detailed what is required of the final product, designers should make choices that they see as an opportunity to design for, are comfortable designing for, or have a personal interest in designing for. It is recommended that one of the age groups detailed in chapter two are chosen, though different models for age groups may be used that may be more broad or narrow. For this example, the chosen age group is 9-12, which may later expand to 9 and up.

4.1.3 Section 1C - STEM Category

When choosing a STEM category, designers may have an idea of a specific STEM topic in mind, such as metamorphosis. If this is the case, designers should broaden their choice to the subject that the topic falls under. In the case of metamorphosis, this could be biology, entomology, or insects. For the example used in this chapter, the two following STEM categories will be chosen:

- Chemistry
- Physics

Although only one category is required, two categories are chosen here in order to provide flexibility in later design work. One category may be dropped later so as to not force the designer to try to combine two categories in a way that cannot be justified.

4.2 Step Two - Definition

After the completion of step one, the process diagram should be filled out as such:

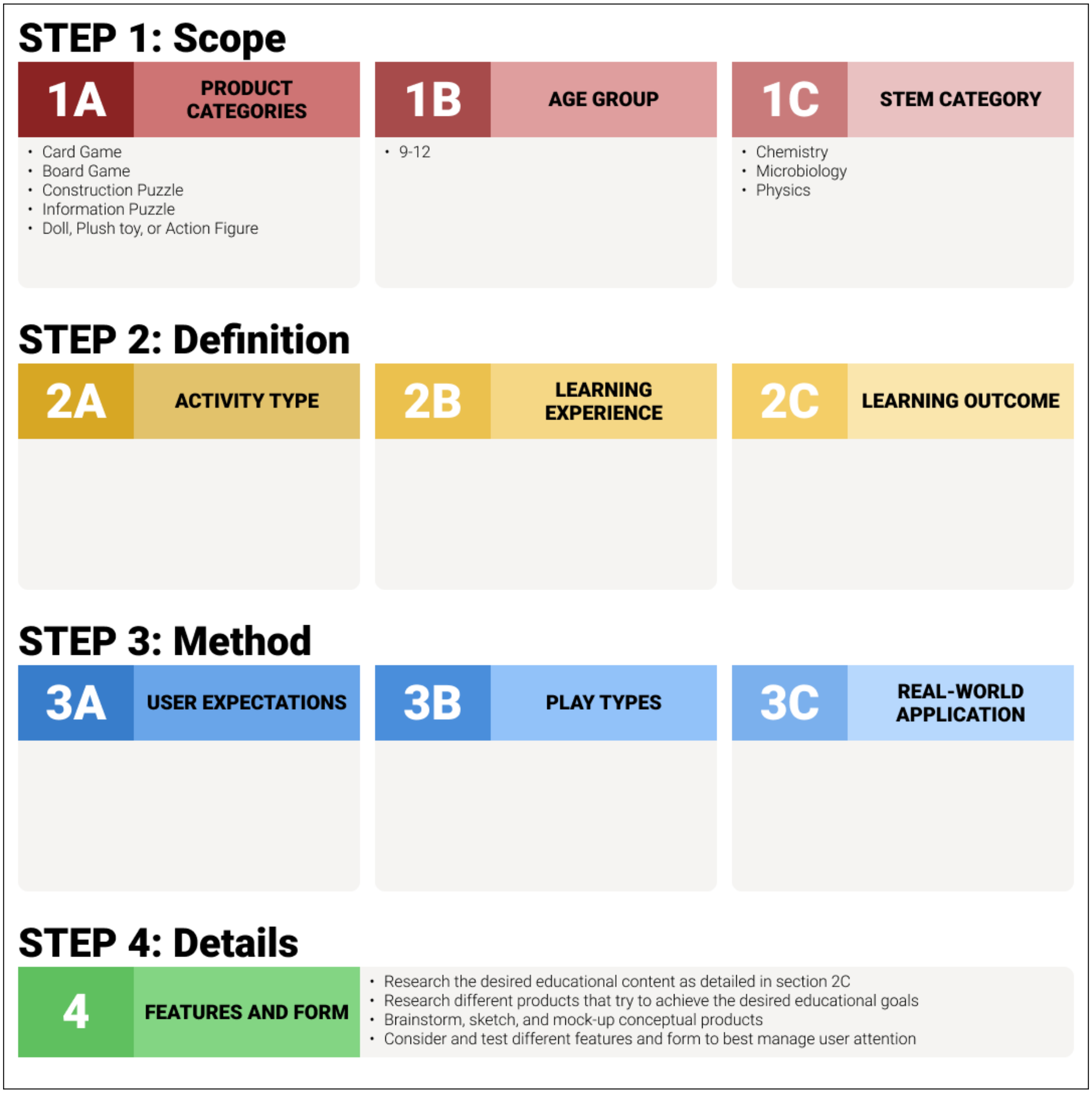

Figure 16: STEM Play Process Diagram with Step 1 Completed

In step two, designers are tasked with detailing the activity types, learning experiences, and learning outcomes that they either predict will be effective at improving users' learning experience or wish to design for.

4.2.1 Section 2A - Developmentally Appropriate Activity Types

Product categories chosen in section 1A may be referenced in an effort to choose effective activity types. For this example, chosen categories and their relationship to activity types are as follows:

Table 9: Section 1A – Chosen Product Category Reference Information of Associated Activities

PRODUCT CATEGORY	COMMONLY ASSOCIATED ACTIVITIES
Dolls, plush toys, and action figures	Role Play
Construction puzzles	Construction, Observation, Analysis, Trial/Error
Information puzzles	Observation, Analysis, Comparing/Contrasting, Answering Questions, Reading, Writing
Board games	Analysis, Trial/Error, Answering Questions, Reading
Card games	Analysis, Trial/Error, Answering Questions, Reading

Referencing the chart above drawn from section 1A, the designer can compare product categories and common activities. As the most commonly shared activity between products in this example, analysis is an easily justifiable choice. Trial and error is also present in a majority of the categories along with reading and answering questions, which may help guide future design decisions. In contrast to these, role play is an outlier. Depending on the designer's personal desires for the project, this may either be excluded for its difference to other categories or included because of some desire or requirement to foster a particular product category or activity type. In this example, at this step, role play will be included to include dolls, plush toys, and action figures in the ideation phase of section 4. With this, the chosen activity types to design for are as follows:

- Analysis

- Trial/Error
- Reading
- Answering Questions
- Role Play

This list of activities may be filtered down or added to in the ideation phase, but for now this acts as a general list to design products that include and excel at fostering at least one of these activities.

4.2.2 Section 2B - Content Driven Learning Experience

In section 2B, designers are tasked with selecting one or more appropriate learning experience types. The list of these experiences is limited to models, simulations, games, and free play. Choices should relate to the chosen product categories and be appropriate for the chosen age group. For the previously chosen product categories in this example, the table from section 1A can be constructed as follows:

Table 10: Section 1A – Chosen Product Category Reference Information of Associated Learning Experiences

PRODUCT CATEGORY	COMMONLY ASSOCIATED LEARNING EXPERIENCE
Dolls, plush toys, and action figures	Simulations, Free Play
Construction puzzles	Models, Games
Information puzzles	Games
Board games	Games
Card games	Games

By referencing the chart above, games can be selected as the most commonly shared experience among categories. In contrast, simulations and free play are only present in the first category. This could lead the designer to only include games as an experience, but if they wish to include another experience as a possible direction to design for later, it should be included here. In this example, the categories that are chosen to be the focus of the project are simulations and games. To reiterate, later ideation may include concepts of other categories, but should include at least one of the included categories and attempt to excel at fostering it.

4.2.3 Section 2C - Developmentally Appropriate Learning Outcomes

With the age group defined as 9-12 and STEM categories of chemistry, microbiology, and physics chosen, realistic learning outcomes based on existing educational models can now be considered. For clarity of project definition and ease of future direction, it is helpful to create learning outcomes that relate specifically to each category separately, even if the end product may be interdisciplinary. For this example, the following learning outcomes can be detailed as such:

Table 11: Section 2C – Brainstormed Example Learning Outcomes

LEARNING OUTCOMES	STEM CATEGORY
Familiarity with lab equipment use procedures	Any category
Ability to mix chemicals in specific orders and amounts	Chemistry
Understanding of why certain chemicals react to produce specific results	Chemistry
Familiarity with atomic structure and purpose of different parts of an atom	Chemistry
Knowledge of processes to study specific features of microscopic subjects	Microbiology
Familiarity with cell structure and function	Microbiology
Understanding of relationship between cells, bacteria, and viruses	Microbiology
Ability to construct simple machines to perform specific tasks	Physics
Ability to combine simple machines to create complex machines	Physics
Ability to calculate physical forces such as momentum, gravity, etc.	Physics

For a more focused project direction, the following categories are chosen to act as the primary learning outcomes to design for, as they are the most specific. However, if there is a concept that does not achieve any of these and instead achieves an objective detailed on the previous list, the end product may still be appropriately justified.

Table 12: Section 2C – Brainstormed Example Learning Outcomes Filtered

LEARNING OUTCOMES	STEM CATEGORY
Familiarity with lab equipment use procedures	Any category
Familiarity with atomic structure and purpose of different parts of an atom	Chemistry
Understanding of relationship between cells, bacteria, and viruses	Microbiology
Ability to combine simple machines to create complex machines	Physics

These will act as possible learning outcomes to achieve, as it is unlikely that one product concept will be able to effectively support all of them.

4.3 Step Three - Method

At this point in the process, clear project goals have been defined, and the diagram can be filled out as such:

Figure 17: STEM Play Process Diagram with Step 2 Completed

The next step in the process is to decide on an appropriate method of achieving these project goals through predicting and meeting user expectations, incorporating a specific play type, and making sure what is learned from the product is applicable to real-world scenarios. This step marks the beginning phases of brainstorming and ideation but comes before resolution of specific features and form.

4.3.1 Section 3A - User Expectations

By considering both the chosen activity types and learning experiences, designers must predict what target users might expect from a product that fits those criteria. In this example, chosen activity types include analysis, trial and error, reading, answering questions, and role play. Chosen learning experiences include simulations and games. One possible method to better connect the two is formulating a question using different combinations of choices detailed in section 2A and 2B. For this example, questions are formed and answered as such:

Table 13: Section 3A – Brainstormed Example User Expectations

WHAT WOULD USERS EXPECT FROM...	ANSWER
...a simulation that requires critical analysis	Activities that focused on sorting through options or information to come to a conclusion
...a simulation that allows for trial and error	A product with repeatable tasks or modular parts and a clear metric of success
...a simulation that requires reading comprehension	A scenario that requires users to gather information for later reference
...a simulation that offers users the chance to answer questions	A scenario that has puzzle-like interactions that act as a checkpoint or metric of success
...a simulation in which users participate in role play	A scenario that allows users to replicate the actions of a professional by using tools or performing actions unique to that field
...a game that requires critical analysis	Options of choice that relate to some metric of success
...a game that allows for trial and error	Decisions with an unknown, but somewhat predictable result that require testing different options
...a game that requires reading comprehension	Details or answers to questions that are hidden within or suggested by text
...a game that offers users the chance to answer questions	Quiz-like questions that are intermittent or final tests that relate to a metric of success
...a game in which users participate in role play	Tests of proficiency in performance of given tasks that replicate real-world tasks

There are no set guidelines for how answers for this section should be formed as long as they are logically understandable in their relation to the previously chosen activity type and learning experience. This list of user expectations acts as guidance for what to include in future ideation and how to justify user-centric design. For simplicity, only the following four sections will be included in the rest of the design process:

Table 14: Section 3A – Brainstormed Example User Expectations Filtered

WHAT WOULD USERS EXPECT FROM...	ANSWER
...a simulation that requires reading comprehension	A scenario that requires users to gather information for later reference
...a simulation in which users participate in role play	A scenario that allows users to replicate the actions of a professional by using tools or performing actions unique to that field
...a game that requires critical analysis	Options of choice that relate to some metric of success
...a game that allows for trial and error	Decisions with an unknown, but somewhat predictable result that require testing different options

4.3.2 Section 3B - Play Types

Next, after considering what learning experiences to design for, an appropriate play type should be selected that aligns with this choice. In this example, simulations and games are chosen. Both of these experience types are most closely associated with the following play types:

- Parallel play
- Associative play
- Cooperative play

During ideation of concepts, focusing on one of these three play types assists in creating an easily justifiable concept of which details can be refined to fit a clearer direction. For simplicity of this example, this choice will be preemptively narrowed down to only associative play. As such, concepts should have a strong focus on associating user actions and some part of the learned content. This can be done through designing to allow either a user's actions to change the outcome of the product's content or some part of the content to have an impact on a user's choices and actions.

4.3.3 Section 3C - Understanding of Real-World Application

At this part of the design process, this section acts as a reminder for the designer to have content and learning outcomes that are applicable to the real world. Because no specific concepts have been designed yet, there cannot be an association detailed here. Later, after a product concept has been developed, the method of relating the learning outcomes to real-world application can be detailed here. This marks the end of the preliminary project brief construction with the process diagram filled out as such:

Figure 18: STEM Play Process Diagram with Step 3 Completed

4.4 Step Four - Features and Form

With the objective of the project clearly specified, the project can now continue into the typical design process of directed research and concept ideation. In this example, the process described in chapter 3.5 will be used, but other design processes or frameworks are also applicable as long as the designer is comfortable with them. The process used here is as follows:

- Research the desired educational content as detailed in section 2C.
    - What are common activities taken within the chosen STEM field?
    - What knowledge is required for one to operate in this field?
    - What, of this knowledge, can be reasonably understood by the target user?
- Research different products that try to achieve the desired educational goals.
    - What approach do these products take to impart knowledge as would be detailed in sections 2A, 2B, 3A, and 3B?
    - What are the benefits of presenting knowledge this way?
    - What are the shortcomings of presenting knowledge this way?
    - Can any part of the educational approach used in researched products be replicated for this product?
- Brainstorm, sketch, and mock-up conceptual products of the chosen product type of section 1A that incorporate as many features detailed in later steps as possible.
    - What features does the product need to have to operate?
    - What features are needed or can be added to improve the quality of the user's educational experience?
    - How open-ended should the use of this product be?
    - What key features should be highlighted to direct the user's attention?
    - How might the product change to visually direct the user's attention?
    - How might the product change to physically direct the user's attention and limit misdirected use?

This process will be followed by an evaluation using the design process diagram and be repeated to refine the concept and then later be checked for any conflicts between the details of each section. Once confirmed to have no outstanding conflicts, the process diagram can be used as selling points that help to communicate key features of the product to both consumers, stakeholders, and other people involved in the future production of the product.

4.4.1 Content Research

The purpose of this step is to research possible specific subjects to use as the educational focus of the product that falls within the more general subjects detailed in section 2C. As designers are unlikely to be experts in the field they are designing for, research at this step is essential. Because multiple STEM categories are considered in this example, each category requires separate research which can be organized in a table as such:

Table 15: Content-Related Research Notes

CONTENT RESEARCH	SUBJECTS OF FOCUS (What is being taught)	EDUCATIONAL FOCUS (What needs to be understood)	RESEARCH NOTES (How to convey what needs to be understood)
Chemistry Lab Equipment	Chemicals Measuring Tools	Using tools to measure amounts, Familiarity with specific chemicals, Chemical identification	Mass - grams on manual triple beam balance, Volume - mL in graduated cylinder, Temperature - degrees on thermometers
Microbiology Lab Equipment	Microscopes Petri Dishes Solutions Standard Procedures	How to use equipment, How to set up petri dishes/slides	Lens zoom - adjusting resolution, Demonstrate preparation process of samples
Physics Lab Experiments	Weights Measuring Tools Physical Forces	Weight comparison measurement, Calculation of momentum/velocity/etc.	Velocity - distance / time Momentum - mass * velocity Adjusting variables to achieve a desired result
Atomic Structure	Atom Interactions Protons, Neutrons, Electrons Elemental Properties	Electron exchange, Chemical equation calculation, Measuring atomic mass	Electrons are shared between atoms like puzzle pieces, Mass is not lost in from reactants to products
Chemistry Lab Actions	Safety Procedures Chemical Mixing	Proper use of equipment, How chemicals interact in nature	Highlight lab dangers and how to prevent them, Common examples of chemical reactions Ex: Oxidation, Lime buildup, Rust, Household products
Cells, Bacteria, and Viruses	Cell Structure Cell Identification Bacteria/Virus Behavior Disease Treatment	How to identify cells/parts of a cell, Cell/organelle function, How diseases are identified, How diseases are treated	Organelles transfer food to cell in a process, Relate organelle function to similar large-scale example Ex: Body, City, Business
Simple/Complex Machines	Simple Machine Use Cases Complex Machine Structure Physical Forces and Work	How to make/use simple machines, When to use complex machines, How to measure output	Different machines have different use cases but can be compared, Directional force can be changed, Specific desired results can be achieved with combinations of parts

Because there is more than one category, these categories can be slimmed down to only the ones that the designer sees an opportunity to design for. In this example, only the following categories will continue to be researched:

Table 16: Content-related Research Notes Filtered

CONTENT RESEARCH	SUBJECTS OF FOCUS (What is being taught)	EDUCATIONAL FOCUS (What needs to be understood)	RESEARCH NOTES (How to convey what needs to be understood)
Atomic Structure	Atom Interactions Protons, Neutrons, Electrons Elemental Properties	Electron exchange, Chemical equation calculation, Measuring atomic mass	Electrons are shared between atoms like puzzle pieces, Mass is not lost in from reactants to products
Cells, Bacteria, and Viruses	Cell Structure Cell Identification Bacteria/Virus Behavior Disease Treatment	How to identify cells/parts of a cell, Cell/organelle function, How diseases are identified, How diseases are treated	Organelles transfer food to cell in a process, Relate organelle function to similar large-scale example Ex: Body, City, Business
Simple/Complex Machines	Simple Machine Use Cases Complex Machine Structure Physical Forces and Work	How to make/use simple machines, When to use complex machines, How to measure output	Different machines have different use cases but can be compared, Directional force can be changed, Specific desired results can be achieved with combinations of parts

4.4.2 Product Research

As often is the case, there may be products that already attempt to accomplish these goals. If any can be found through research, their benefits and shortcomings should be analyzed and noted. In this example, research is collected in pictures and notes as such:

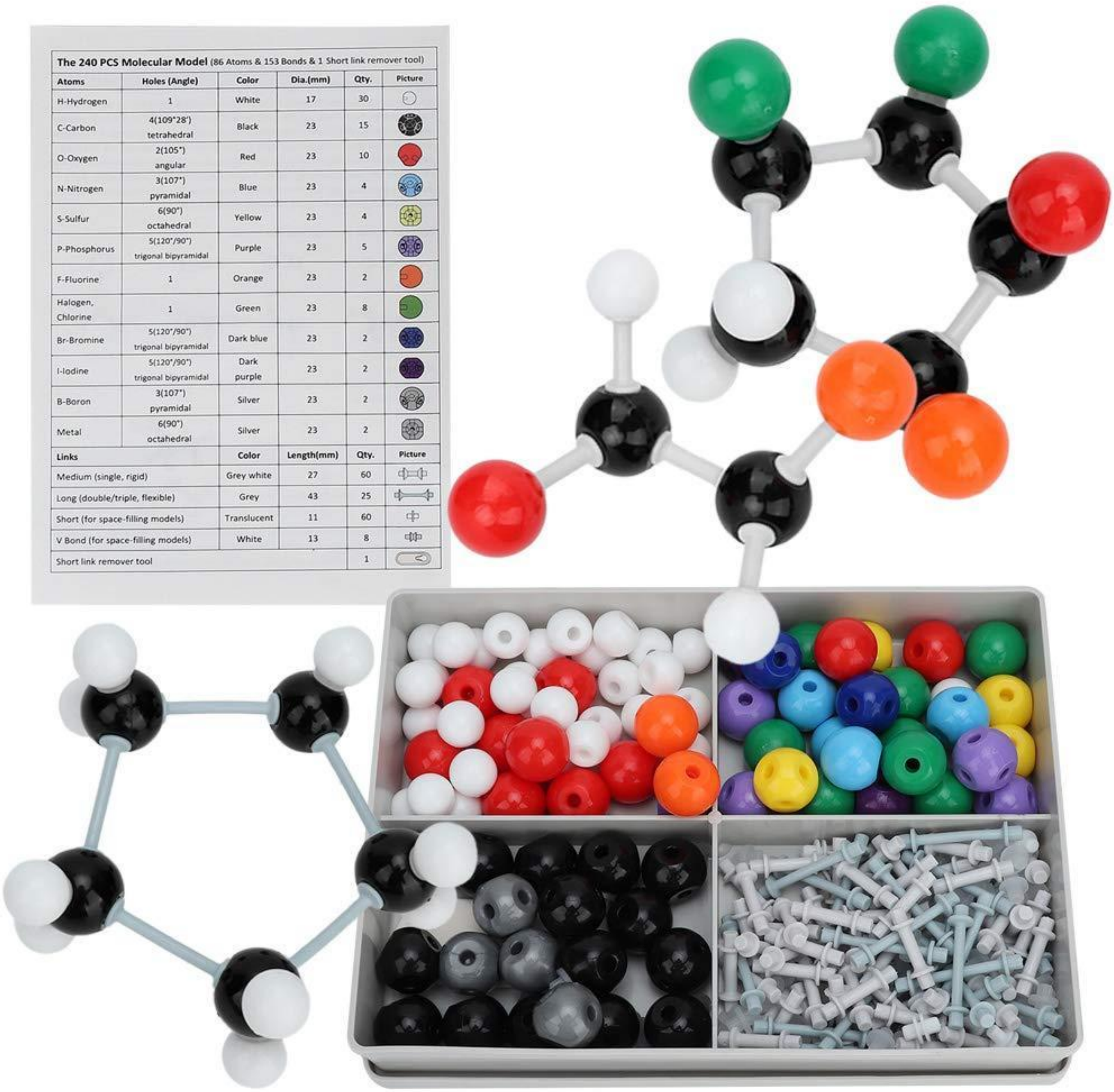

Figure 19: Atom Construction Model Toy (Amazon.ca, 2025)

Table 17: Analysis of Atom Construction Model Toy

PRODUCT	PROS	CONS
Atomic Structure Toy	Visible/tangible connections between atoms Distinct modular atoms of different elements	Unclear reason for connections Unclear reactive limitations Limited educational direction
NOTES	Size could be more distinct Electrons could be included	Could be modular puzzle instead Reactive connections could be limited by form

Figure 20: Simple Machines Play Kit (Learning Resources US, 2025)

Table 18: Analysis of Simple Machines Play Kit

PRODUCT	PROS	CONS
Simple Machines Kit	Easily tangible simple machines, Visible demonstration of work	Weight is light enough to lift, Amount of force applied not visible, Lacks specific goal
NOTES	Combination of machines possible, Possibility of shared load demonstration	Incorporate limiter, Create specific goal requiring directional work

Figure 21: Pandemic Board Game (Amazon.com, 2025)

Table 19: Analysis of Pandemic Board Game

PRODUCT	PROS	CONS
Pandemic Board Game	Large-scale simulation of realistic scenario, Characters encourage role play	Specific actions of discipline unknown, Themed and not instructional or educational
NOTES	Role play element could be stronger, Actions are not content-related	Focus on a different scale of same topic

These pictures and highlighted details are used as inspiration and key educational elements can be replicated in the next step during sketch ideation. Likewise, noted shortcomings can be avoided during ideation.

4.4.3 Sketch Ideation

Any number of ideas may be sketched and tested in this section until the designer is comfortable moving forward with one that they think is worth developing further. For brevity, only one idea will be expanded upon here. In this example, a card game is conceptualized with rules that allow players to simulate the process of identifying and curing a disease. The design direction of the design process diagram is first detailed specifically for this concept in order to keep its design focused on achieving as many of these goals as possible.

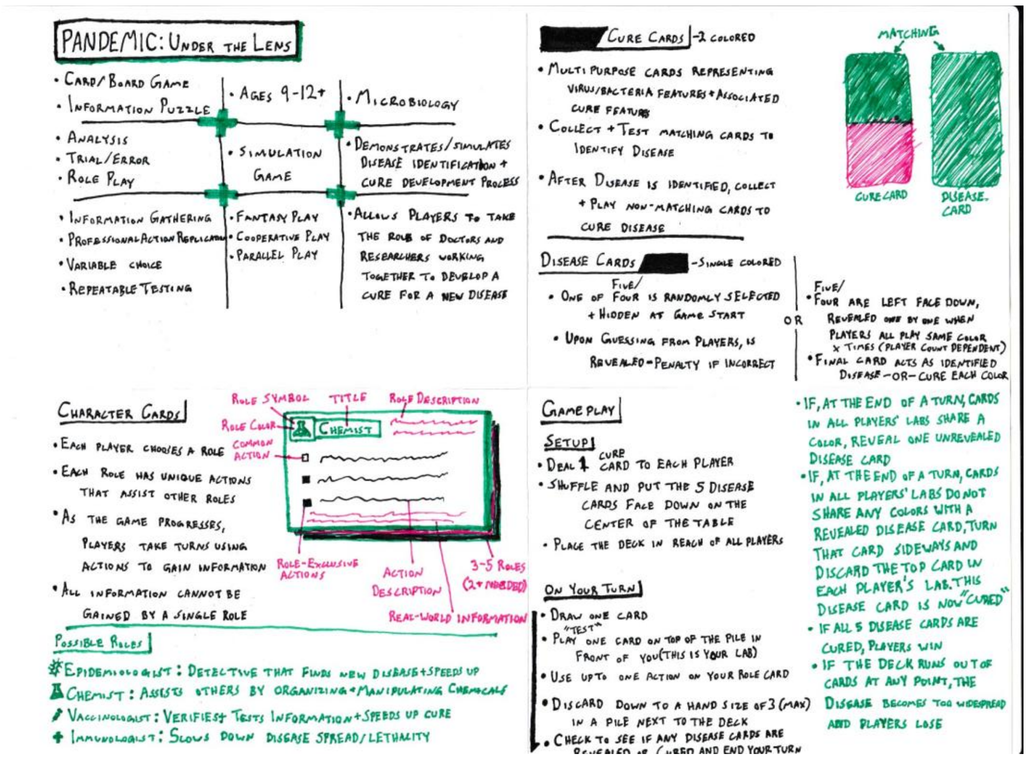

Figure 22: Example Rules of Card Game Concept

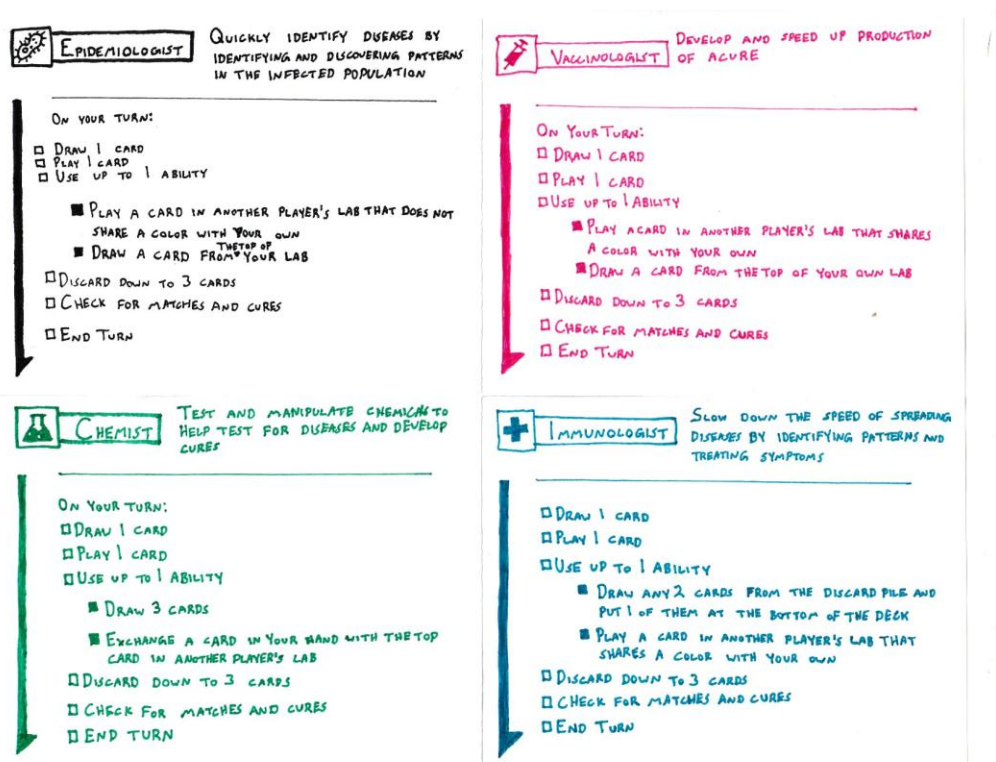

Figure 23: Example Role Cards of Card Game Concept

The board game Pandemic is used as inspiration for this concept. This concept will fit into the categories of a card and board game as well as an information puzzle. As it is intended for ages 9 at the youngest, drafted rules are kept simple, so as to not be too confusing for players of that age or require an unrealistic amount of experience with complex subject matter. With the STEM category of microbiology selected, content should be generalized or kept at an introductory level and not require too much specific knowledge of specific microbiology-related subjects.

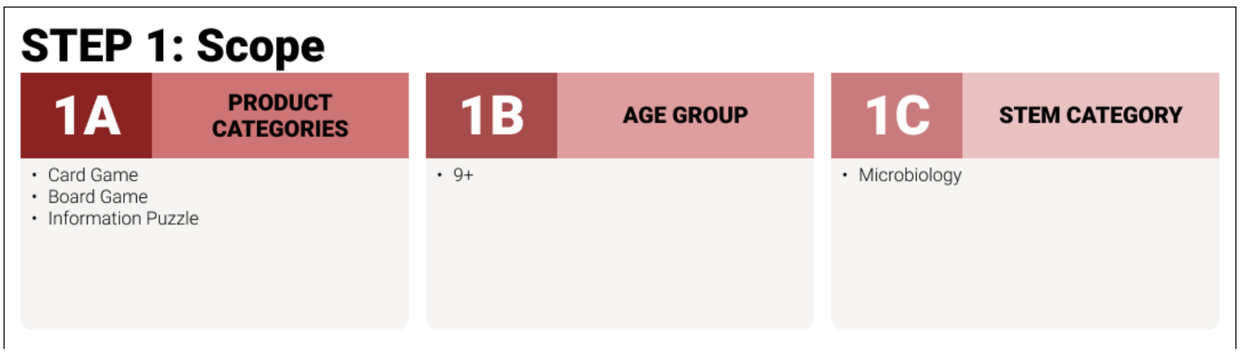

Figure 24: Step 1 Information of the Product Concept

Now that the general type of product has been decided, the theme is used to inform player interaction. With Pandemic as the inspiration, it was noted that, while STEM themed, Pandemic lacks much actionable knowledge. Players aren't made familiar with any specific activity within the subject matter of the imagined scenario, which is especially lacking for its youngest intended audience of 8 years old. Pandemic's large-scale approach of identifying and curing diseases is able to be used as a pain point for this concept, inspiring the design to be more personal and having more opportunities for role play. Each player is imagined to take the role of a specialist that has different ways of working with other players to progress to a common goal. In this way, the next step is decided.

Activities that players will perform can be categorized as analysis of multiple decisions and different situations, finding the most optimal outcome to answer questions, and role play in which they insert themselves into the role of professionals in the field of microbiology. The concept's activity types and product categories lend the game to be classified as a simulation game, defining the learning experience. As the game is heavily focused on familiarity with the actions of professionals, the learning outcome is intended to come from the cooperation of players to simulate the process of identifying and creating a cure for a disease. Knowledge of detailed processes or familiarity with high-level microbiology concepts are not required to be taught, as these would be inappropriate for the target age range. Instead, the STEM educational value of the game comes from the familiarity with specific professions, as well as the knowledge of the importance of those roles through each of them being better at performing certain tasks than other roles.

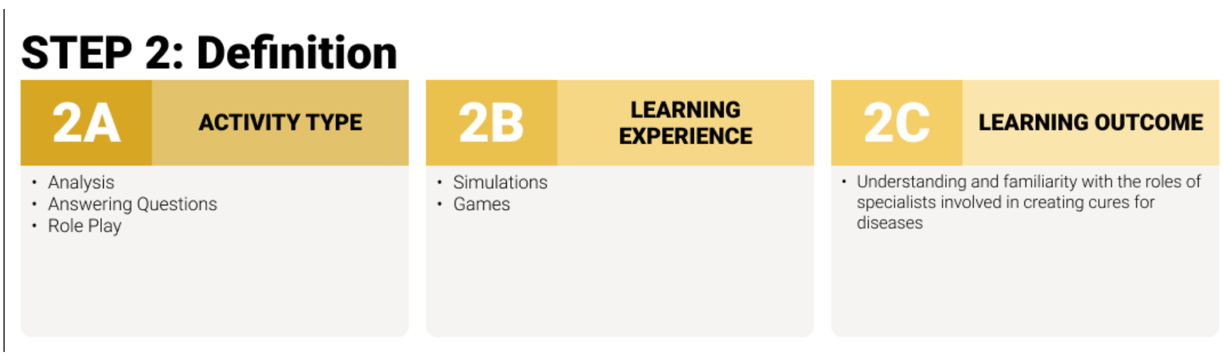

Figure 25: Steps 2 and 3 Information of the Product Concept

Because the goal of the game is to identify a disease in the context of a card game, this lends itself to using cards to perform cooperative tasks, such as matching. In this draft of the game, matching colors are conceptualized as the means by which to simulate the performance of cooperative tasks. To simplify the gameplay, only two types of playing cards are used. As the goal of the games is to identify and cure a disease, two steps or phases of the game are noted to be the goal of the game. As is the case in the original game, Pandemic, this concept uses the risk of a disease outbreak as the losing condition and the curing of the disease as the players' collective win condition, with no other metric of success to compete against. This is done to encourage full cooperation, communication, and strategic planning between players, further amplifying the educational value for the intended audience.

In terms of gameplay, winning is achieved flipping, or identifying, and removing, or curing, a certain number of cards representing a disease. Losing is denoted by cards in the deck running out, representing running out of time to cure a disease before an outbreak.

Because each role's real-world counterpart has different specialties in relation to diseases, so too should the roles within the game. Four character cards are created, each with unique abilities that slow down, speed up, or interact with different parts of the game in unique ways. Character cards are named epidemiologist, vaccinologist, chemist, and immunologist, as these professions each play a role in the identification, prevention, and treatment of diseases.

Epidemiologists in the real world specialize in identifying outbreaks and discovering patterns in infected populations. This description is written as flavor text on the card and the gameplay of the role card allows players to perform actions that are most appropriate in the identification phase of the game.

In contrast to epidemiologists, vaccinologists are focused on the creation of vaccines, so their role within the game is better suited to perform the action of curing the disease cards rather than identifying them.

The counterpart to the chemist role is the immunologist role. Immunologists slow down the speed at which diseases spread by identifying patterns and treating symptoms. As such their in-game counterpart is better in the curing of diseases than identification, though not as effectively as the vaccinologist. To further simulate the real-life profession, the immunologist role is also given the unique ability to put cards back in the deck, which buys the players more time to cure the disease before an outbreak occurs and they lose.

Chemists deal with testing and manipulating various chemicals to achieve results in a variety of cases. As such, the role within the game is not specific to either the identification or curing phases and instead improves card manipulation for the players at the cost of the built-in game timer of running through the deck. To simulate the unpredictability of chemistry in the testing of new diseases, this role offers players a high-risk, high-reward style of gameplay.

All of the abilities in some way affect the playing and drawing of cards in different ways that either match or avoid matching specific colors, representing the disease being identified and cured. At this point, the concept has enough details to fill out each section of the process diagram and can be evaluated against it to measure how successful it is and to identify changes that can be made to improve it.

4.5 Product Evaluation and Alteration

Now that the product concept has been created, each section of the process diagram is filled out to include as many appropriate details as possible. All details listed should be filled out in their respective categories and be associated with the overall goal of creating an educational product. The diagram in this example is filled out as such:

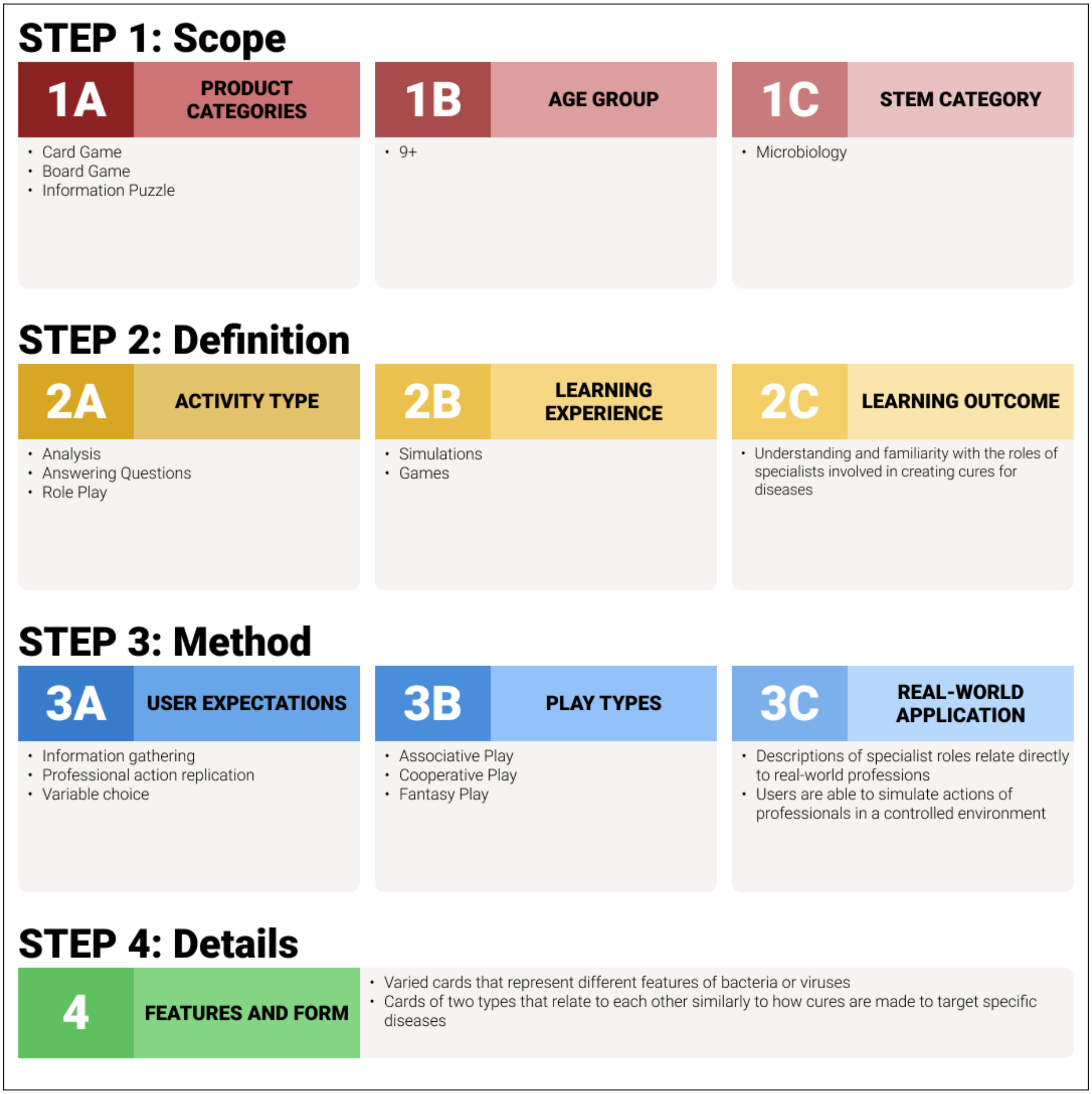

Figure 26: Adjusted STEM Play Diagram

When evaluating the product, inconsistencies, conflicts, and shortcomings can be identified and adjusted for by relating details using the chart below.

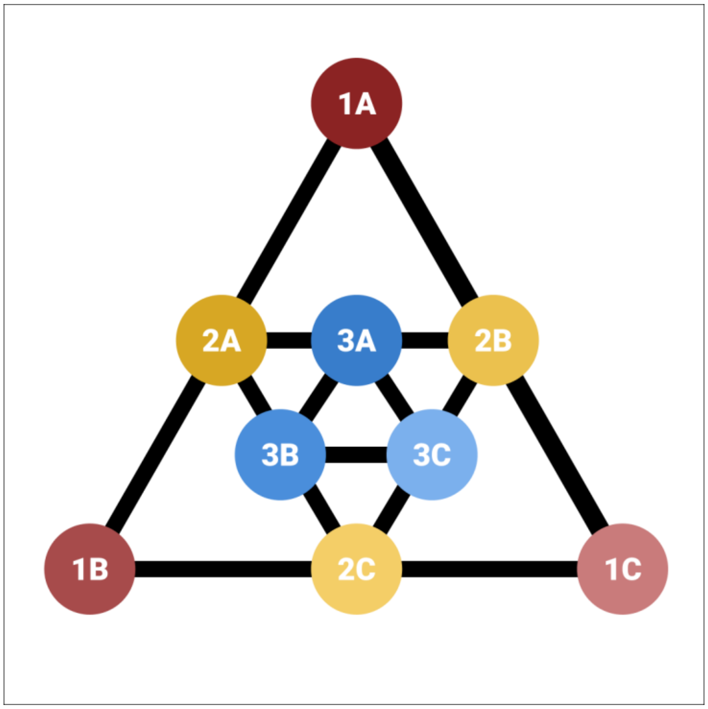

Figure 27: STEM Product Conflict Diagram

In order to determine the effectiveness of the design, the most apparently related features of the concept that relate to each category in the diagram are chosen and evaluated by asking the following questions:

- Does the chosen part of the product communicate its purpose well?
- Is the chosen part of the product able to be understood by the target user?
- Is the chosen part of the product able to be interacted with with little obstruction?

If the answer to any of these questions is no, changes must be made to the design. Either the chosen feature another existing feature must be improved or removed, or an additional feature must be added in order for the product as a whole to appropriately meet the expectations set in the design brief.

After comparing entries, 3C was found to be weak and needed more explanation or clearer simulation. The most related feature of the game was the role cards and their abilities, which did not communicate their purpose well. It was then suggested that role-specific actions have more relation to specific actions taken by real-world professionals. This is done through being named by specific tasks performed within their respective fields and the inclusion of a brief description of each task.

Figure 28: Updated Role Cards with Ability Descriptions

Additionally, cards using simple colors are not readily recognizable as representing different aspects of a disease or different chemicals used in a cure. To fix this, symbols are printed on the cards and disease cards are named to create a more understandable and more immersive experience for the players.

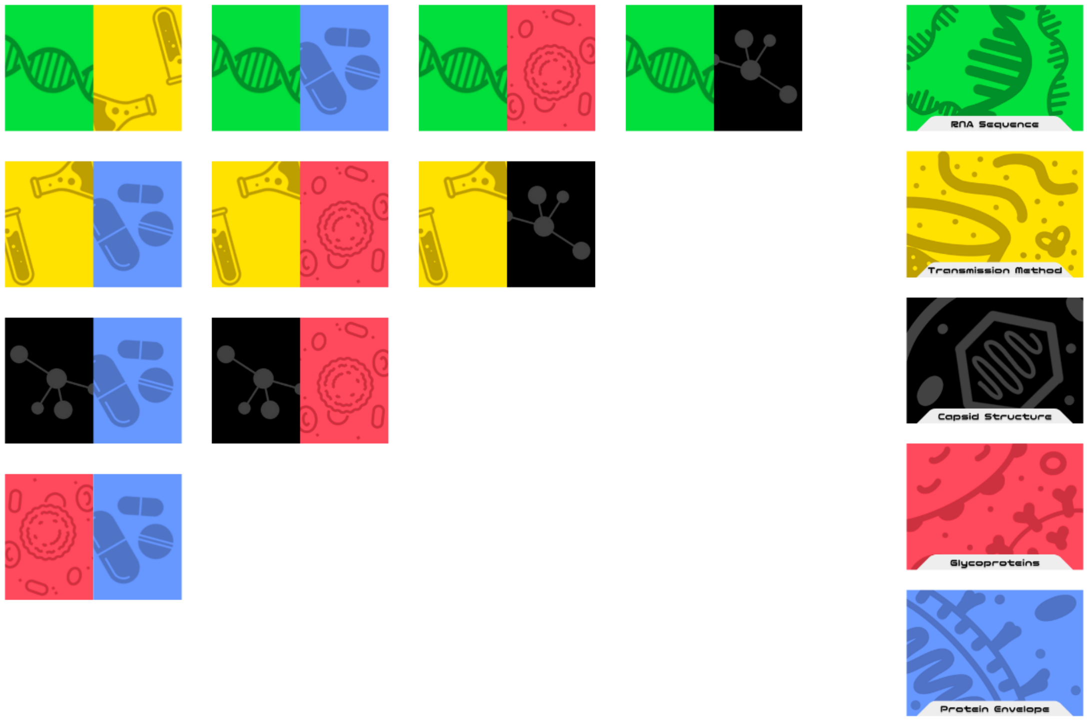

Figure 29: Draft of Card Designs

Art for the product is then created and rendered to put on display the contents of the box. The imagery of a close-up shot of a doctor looking at a microscope is specifically selected to communicate that players will be simulating this and other similar actions within the game. Additionally, disease cards are named to relate them to different aspects of a virus that must be considered in the creation of a cure. After this, an introductory scenario paragraph is written to communicate the setting and set the thematic tone of the game. This could be printed in the first pages of the game's rulebook or on the back of the box to assist in the advertisement for the game. To reiterate, this type of simulation gives the player a personal, and understandable connection to the game's STEM subject matter. For a more detailed description of the named

STEM elements of the game, additional information is written in the rulebook of the game if players wish to deepen their understanding of the actions they are performing and the features of the virus they are creating a cure for. The learning objective in section 2C was decided to be "Understanding and familiarity of specialists involved in creating cures for diseases" and the real-world connection of section 3C was detailed as "Descriptions of specialist roles relate directly to real-world professions" and "Users are able to simulate actions of professionals in a controlled environment". The names of the disease cards, descriptions on role cards, and the information presented in the reference guide of the rules meets these requirements by creating a clear connection between player action and thematic content in a way that simulates real-world concepts and practice. This, unlike many STEM-themed products on the market today, fosters actionable knowledge that players can take into future learning experiences rather than simply utilizing decorative elements that are absent of context. After making these changes to fix the issue highlighted in the conflict diagram, the concept can be fully justified as a STEM product and can move to later stages of development and production.

Figure 30: Rendering of Under the Lens Board Game Concept

The rules for the game are presented as follows:

Under the Lens – A game for 2-4 players ages 9 and up

Welcome to Under the Lens! A new, mysterious disease is at risk of spreading across the globe. Luckily, it is currently contained within a remote city. It is your job to take on the role of a specialist and work together with your team to identify and create a cure for the disease before an outbreak occurs and it spreads to the general population. Will your team of scientists be able to stop the pandemic?

CONTENTS

4 Role Cards

5 Disease Cards

50 Cure Cards

SETUP

Shuffle the 5 single-color disease cards and place them face-down in a row in the center of the table.

Shuffle the dual-color cure cards and place them in a deck face-down next to the disease cards.

Deal 1 cure card to each player.

Each player chooses 1 role card and places it in front of them.

ON A PLAYER'S TURN

Players must perform the following actions in order:

Draw 1 card.

Play 1 card vertically in front of your role card. This is your lab. The color facing away from you is considered active. Both colors are considered to be in your lab.

Choose up to 1 ability to use on your role card.

Discard down to a maximum hand size of 3.

Check to determine if there are any matches to identify part of the disease.

Check to see if part of the disease is cured.

End your turn and pass play to the player to your left.

RULES

Players take turns playing cards to match each other or avoid matching revealed disease cards.

If, at the end of a player's turn, every player has a cure card in their lab of the same active color, reveal 1 unrevealed disease card this part of the disease is now considered to be identified.

If, at the end of a player's turn and after checking for matching colors, every player has a cure card in their lab that does not share a color with a revealed disease card, select up to 1 unmatched disease card and remove it from play. This disease card is now considered cured. If this is done, discard all cards in players labs.

If a cure card enters a player's lab in any way, first discard any existing cards in that player's lab.

WINNING THE GAME

All players win if they manage to cure all disease cards before running out of cards in the deck. This signifies a cure for the disease being developed and given to infected patients.

LOSING THE GAME

All players lose if the deck runs out of cards. This indicates that the players have failed to create a cure for the disease before an outbreak of the disease occurred.

REFERENCE INFORMATION

Epidemiologist – Scientist that studies the cause and treatment of disease outbreaks.

Chemist – Scientist that handles the combination and reactivity of chemicals to produce desired results through experimentation and research.

Vaccinologist – Scientist that deal with the creation and testing of new vaccines.

Immunologist – Doctor that diagnoses, treats, and finds means to lessen the severity of immune disorders.

RNA (Ribonucleic acid) – Nucleic acid that controls the synthesis of proteins. Many viruses use RNA to carry genetic information for reproduction.

Transmission – Viruses can spread by different means, usually through water, air, blood, or by interactions with animals. Different viruses spread faster through different means and survive in unique environments.

Capsid – The protein shell protecting the genetic material within a virus.

Glycoproteins – Proteins that viruses use to attach to cells in order to infect a host.

Protein envelope – Outer layer of proteins that surround the outside of a virus.

Conclusion

The increasing prevalence of the term “STEM” across educational and commercial domains has created a need for clarity, consistency, and accountability in its use—especially in the labeling of products as "STEM." As this thesis has shown, the absence of a standardized definition contributes to consumer confusion and undermines the educational value associated with STEM branding.

Through an in-depth examination of STEM as both an educational framework and a marketing label, this study has developed a comprehensive definition that reflects both pedagogical intent and learning experience. Furthermore, by integrating research on play-based learning and developmental psychology, the thesis has produced a set of practical guidelines to inform the design and evaluation of STEM products. These guidelines serve as a bridge between consumer expectations and educational outcomes, promoting transparency and integrity in product development.

Ultimately, this work underscores the importance of aligning terminology, design, and intent in the rapidly evolving field of STEM education. By establishing a clearer standard for what constitutes a STEM product, this thesis lays the groundwork for more meaningful consumer engagement, improved product design, and sustained public trust in STEM as a vital educational initiative.

Future Study

To expand on the findings presented in this thesis, further study of STEM education and its relevancy to product design may be conducted. Specifically, defining what the specific requirements for a STEM terminal are to be defined as such would assist in the creation of appropriate learning outcomes. Additionally, the efficacy of the guidelines may be better evaluated after a larger sample size of results exists.

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