

Fostering Entrepreneurial Mindset through a Hands-on Design Project in a Mechanism Design Course

Dr. Haolin Zhu, Arizona State University

Dr. Haolin Zhu earned her BEng in Engineering Mechanics from Shanghai Jiao Tong University and her Ph.D. in Theoretical and Applied Mechanics from Cornell University, with a focus on computational solid mechanics. Dr. Zhu is a Senior Lecturer of the freshman engineering education team in the Ira A. Fulton Schools of Engineering at Arizona State University (ASU) and the recipient of the Fulton Outstanding Lecturer Award. In this role, she focuses on designing the curriculum and teaching in the freshman engineering program and the mechanical engineering program. She is also the Assistant Director of the NAE Grand Challenges Scholars Program (GCSP) at ASU and works closely with the Director to ensure the success of the program. Dr. Zhu has also been involved in the ASU ProMod project, the Engineering Projects in Community Service program, the Engineering Futures program, the Global Freshman Academy/Earned Admission Program, and the ASU Kern Project. She was a part of the team that designed a largely team and activity based online Introduction to Engineering course. She has also co-developed two unique MOOCs, Introduction to Engineering and Perspectives on Grand Challenges for Engineering for the Global Freshman Academy/ASU Earned Admission Program. Her Ph.D. research focuses on multi-scale multiphase modeling and numerical analysis of coupled large viscoelastic deformation and fluid transport in swelling porous materials, but she is currently interested in various topics in the field of engineering education, such as innovative teaching pedagogies for increased retention and student motivation; innovations in non-traditional delivery methods, incorporation of the Entrepreneurial Mindset in the engineering curriculum and its impact.

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Abstract

This paper describes the implementation of a hands-on design project in a mechanical engineering course, Mechanism Design and Analysis. The hands-on design project provides students with an opportunity to apply their technical skills in a real work setting while also exercising their entrepreneurial mindset to ensure that their design meets not only technical requirements but also unmet customer needs and creates added value for their customers. The course is a 3-credit junior level technical elective course that introduces the fundamentals of mechanisms and focuses on the kinematic analysis and synthesis of mechanisms. The design project implemented in this course is an open-ended group project that involves the investigation of the toy market, identification of an opportunity, and the design, prototyping, and analysis of a mechanical toy that fulfills the opportunity identified. This study focuses on understanding how the student groups demonstrated the three C's as defined by the Kern Entrepreneurial Engineering Network's (KEEN) framework for entrepreneurial mindset: *curiosity*, *connections*, and *creation of value*, through the analysis of project final written deliverable submissions from three offerings of the course. More specifically, evidence found in the project written deliverable submissions that showed demonstration of each of 17 entrepreneurial behavioral outcomes for the three C's was noted by two raters independently and discrepancies were discussed until consensus was reached.

It has been found that all 54 student groups have demonstrated at least one entrepreneurial mindset behavioral outcome for *each* of the three C's, more than 85% of the 54 groups have demonstrated at least one other entrepreneurial mindset behavioral outcome related to *each* of the three C's, and more than 70% of the groups have demonstrated one other behavioral outcome for *curiosity*.

In this paper, the details of the project and its implementation will be described. The insights gained from the analysis as well as the specific ways in which student groups demonstrated each of the 17 entrepreneurial mindset behavioral outcomes will also be shared and discussed.

Introduction

In today's global economy, engineering graduates need to be prepared to possess both a strong technical skill set and an entrepreneurial mindset (EM) to drive innovations. According to Kriewall and Mekemson [1], "an entrepreneurial minded engineer (i.e., an engineer instilled with the entrepreneurial mindset) places product benefits before design features and leverages technology to fill unmet customer needs". So, an engineer that is entrepreneurially minded can

focus on unmet customer needs and consider the benefits and impact of their designs in addition to their technical details. Many engineering programs and educators have now recognized the importance of instilling an entrepreneurial mindset and many efforts have been made to improve programs and curriculum to incorporate opportunities for students to exercise their entrepreneurial mindset. The Kern Family Foundation has established a network of institutions that are committed to changing their pedagogy to develop entrepreneurial mindset in undergraduate engineers, known as KEEN (Kern Entrepreneurial Engineering Network). KEEN has established an entrepreneurial mindset framework that involves the three C's: *curiosity*: "students will demonstrate constant curiosity about our changing world and explore a contrarian view of accepted solutions", *connections*: "students will integrate information from many sources to gain insight and access and manage risk" and *creating value*: "students will identify unexpected opportunities to create extraordinary value and persist through and learn from failure" [2]. Within mechanical engineering, various efforts have been made to incorporate the entrepreneurial mindset into the curriculum. For example, Gerhart used EML (entrepreneurially-minded learning) in a fluid mechanics course by incorporating stakeholders, opportunity identification, and value creation into problem-based learning [3]; Hennessey incorporated EML into a dynamics course [4]; Mehta et al. implemented EML in a manufacturing processes course [5]; Mollory et al. developed EML modules for a sophomore level Statics course [6]; Baqersad et al. implemented EM in a mechanics of materials course [7]; Farina et al. developed a project module to help increase students' curiosity, one of the three C's from KEEN's EM framework, about cooling systems in a thermodynamics course [8]; similarly, Miller also developed a module in a manufacturing course that aims to increase students' curiosity [9]. Most of these efforts were seen in lower division courses. Opportunities for students to merge EML with technical content introduced in higher level courses are rare [10]. Few efforts have been seen in junior level courses, especially in a course that focuses on mechanism analysis and design.

In addition, though many mechanical engineering programs offer opportunities for students to perform hands-on design, these opportunities are usually only offered in first year introductory courses and/or senior capstone courses [11]. Only few efforts have been found in the literature that provide mechanical engineering students with the opportunities to perform hands-on design in their sophomore or junior years. For example, Mascaro et al. at University of Utah implemented new laboratories which involve hands-on design in the first and second years of the mechanical engineering program [12]; Al Hamidi, et al., discussed similar efforts in the Mechanical Measurements course at Texas A&M University at Qatar [13]; Hodges and Sullivan implemented several projects in the Design of Mechanical Systems course, which involved fabrication of students' designs in the machine shop [14]. However, these efforts do not involve the development of an entrepreneurial mindset.

The author has tried to implement a group-based hands-on design project in a junior level mechanical engineering course, Mechanism Design and Analysis, which was previously taught

in the form of traditional lectures, problem-based homework assignments, and exams. This 3-credit course is offered as a technical elective to students in the mechanical engineering program at Arizona State University. It introduces the fundamentals of mechanisms and focuses on their kinematic analysis and synthesis. Besides technical outcomes, the hands-on design project implemented in this course also aims to achieve three other outcomes: it provides junior level mechanical engineering students with an opportunity to perform hands-on design; it fosters the development of an entrepreneurial mindset; and it helps students to visualize how various mechanisms work. This study focuses on understanding how well the second of these three outcomes has been achieved, i.e., fostering the development of an entrepreneurial mindset. More specifically, project final deliverable submissions were analyzed to identify ways in which the student groups have demonstrated the three C's, *curiosity*, *connections*, and *creation of value*.

In the sections to follow, the design and implementation of the hands-on team design project will be described, and the insights gained from the analysis of student project final deliverable submissions will also be shared and discussed.

Project Description

In the project, students self-select groups of 3 or 4 and work on the creation of a toy design prototype during the second half of the semester. Their designs are required to include at least one linkage and at least one gear train or cam and follower, and it could be manually operated. It is suggested that their design prototype be made using wood, or with parts that are laser-cut, or 3D printed. The final deliverables of the project include a physical prototype of the design, a poster, and a final written deliverable. All groups present their designs at a poster session near the end of the semester. A project like this focuses on technical skills and employs problem-based learning (PBL). It is still a valuable learning and hands-on experience for students, but it does not help foster the development of an entrepreneurial mindset.

Fostering the development of an entrepreneurial mindset requires EML (entrepreneurially minded learning). According to Gerhart and Melton, "EML incorporates a pedagogical emphasis on discovery (i.e., curiosity), opportunity identification, and value creation, which is built upon active pedagogies such as problem-based learning," and EML should "incorporate stakeholders, discovery, opportunity identification, and value creation." [3] Thus, to help foster the development of an entrepreneurial mindset, a fictional company Toys Inc. was introduced in the project as the primary stakeholder. Student groups are asked to submit a proposal to this fictional startup toy company with an innovative toy design that will become the company's signature product. They are also asked to identify an opportunity, select a market, identify potential customers and their needs, and validate market interest. The final poster session has become a toy expo for Toys Inc. to evaluate the design ideas. The final written project deliverable has become a written proposal submitted to Toys Inc., which summarizes details of the design and

convinces Toys Inc. why their design should be selected as their signature product through the discussion of the opportunity and value creation. This project incorporates the entrepreneurial mindset because the goal is to identify a market and an opportunity and create an effective design that creates extraordinary value for the company and its customers. During this process, students must exercise their curiosity to determine what type of information will be useful, identify various pieces of information, both technical and non-technical, and integrate all the information gathered.

The following questions were provided for student groups to consider in their design process:

- Who are the users? Who are the buyers? What are their needs? How does your design address these needs?
- What is your target cost range? Is it going to be competitive on the market?
- How is your design unique and different from others on the market? Does your design fill a void in the market?
- Can your design be mass produced easily?
- How will the toy be operated? What is the desired output motion?
- How will motion be transferred from the input to the output? What mechanisms can be used to achieve this?

The project is assessed based on the three final deliverables submitted. More specifically, the grade breakdown of the project is as follows:

Table 1. Project Grade Breakdown

Item	Points
Design Prototype	100
Poster	30
Proposal Document	120

The project poster and prototype are assessed at the project poster session based on the criteria shown in Tables 2 and 3, respectively, on a scale of 1-5 (1=poor; 2=below average/needs improvement; 3=average; 4=good; 5=excellent).

Table 2. Project Poster Assessment Criteria

Is the poster visually pleasing to the viewer yet professional?	1	2	3	4	5
Is the poster informative and clear?	1	2	3	4	5
Is the content well organized and formatted?	1	2	3	4	5
Does the poster allow you to gain a good understanding of all aspects of the design?	1	2	3	4	5

Is the poster convincing (does it provide information that would convince Toys Inc. to invest in the design and choose it as their signature product?)	1	2	3	4	5
Group members communicated effectively about their design and were knowledgeable about their design.	1	2	3	4	5

Table 3. Project Prototype Assessment Criteria

Is the design prototype fully functional?	1	2	3	4	5
Does the design meet all design requirements and the design goals set by the group?	1	2	3	4	5
Is the toy appropriately designed for the target market?	1	2	3	4	5
Does the design properly address all the customer needs and the opportunity identified?	1	2	3	4	5
Is the design easy to play and/or interact with and/or visually attractive for the potential customers identified?	1	2	3	4	5
Is the design cost competitive?	1	2	3	4	5
Is the design unique on the market, i.e., does it fill a void in the market?	1	2	3	4	5
Does the design create added value for the stakeholders?	1	2	3	4	5
Is the design easily scalable?	1	2	3	4	5
Does the prototype properly represent the design? Is it well crafted?	1	2	3	4	5

All the technical knowledge and skills are assessed using the proposal document. In the proposal document, students must describe the process of mechanisms synthesis, provide technical details about their design, and present kinematic analysis of their design.

Understanding Student Demonstration of the Three C's - Method and Results

To understand in what ways the student groups have demonstrated the three C's through this project, the proposal documents submitted by student groups from three offerings of this course were analyzed. More specifically, evidence was noted if a student group has demonstrated one of the 17 EM behavioral outcomes based on the framework defined by London, et al. that operationalizes the three C's [15]:

Curiosity

- a. Critically observes surroundings to recognize opportunity

- b. Explores multiple solution paths
- c. Gathers data to support and refute ideas
- d. Suspends initial judgement on new ideas
- e. Observes trends about the changing world with a future-focused orientation/perspective
- f. Collects feedback and data from many customers and customer segments

Creation of value

- g. Applies technical skills/knowledge to the development of a technology/product
- h. Modifies an idea/product based on feedback
- i. Focuses on understanding the value proposition of a discovery
- j. Describes how a discovery could be scaled and/or sustained, using elements such as revenue streams, key partners, costs, and key resources
- k. Defines a market and market opportunities
- l. Engages in actions with the understanding that they have the potential to lead to both gains or losses

Connections

- m. Articulates the idea to diverse audiences
- n. Persuades why a discovery adds value from multiple perspectives (technological, societal, financial, environmental, etc.)
- o. Understands how elements of an ecosystem are connected
- p. Identifies and works with individuals with complementary skill sets, expertise, etc.
- q. Integrates/synthesizes different kinds of knowledge

This framework is one of the few efforts to systematically map KEEN's three C's to specific student behavioral outcomes and it has been used in entrepreneurial mindset assessment efforts and/or validated by a few authors [16-18].

A total of 54 group proposal documents for the project were analyzed. Out of these 54 group proposal documents, 27, 18, and 9 were from each of the three offerings, respectively. Two raters were involved in the analysis. These two raters analyzed 4 of the proposal documents together and discussed and confirmed indicators of demonstration of the behavioral outcomes. After that, the two raters analyzed the remaining 50 proposal documents independently. The results were then compared and discussed until agreement was reached for any discrepancies that arose from the independent analyses. If there was an indicator(s) found in a proposal document for a specific behavioral outcome, that group was marked to have demonstrated that behavioral outcome. The specific way(s) in which the group has demonstrated that behavioral outcome was also noted. Example quotes from the proposal documents were also recorded. During the analyses, behavioral outcomes *b*, *g*, *k*, and *p* were not considered from student project submissions, because student groups were required to consider multiple solution paths, the project is still

technical in nature and students are required to apply technical skills and knowledge learned from the course to develop their design, they were required to identify a market, and the project is group based that requires individuals to work together. All groups were considered to have demonstrated these four outcomes.

The table below shows the number of groups that demonstrated each of the 17 behavioral outcomes.

Table 4. Number of groups that demonstrated each of the 17 EM behavioral outcomes

EM Behavioral Outcome	Number of groups that demonstrated the outcome (Total n=54)	Percentage of groups that demonstrated the outcome (Total n=54)
<i>Curiosity</i>		
a	28	51.9%
b	54	100%
c	39	72.2%
d	50	92.6%
e	20	37.0%
f	15	27.8%
<i>Creation of value</i>		
g	54	100%
h	0	0%
i	46	85.2%
j	13	24.1%
k	54	100%
l	1	1.9%
<i>Connections</i>		
m	0	0%
n	15	27.8%
o	0	0%

p	54	100%
q	46	85.2%

The results suggest that all groups from all three offerings of the course have demonstrated at least one behavioral outcome for each of the three C's. More than 85% of the groups have demonstrated at least one other behavioral outcome for each of the three C's. And more than 70% of the groups have demonstrated one other behavioral outcome for *curiosity*. Examples of ways in which the groups have demonstrated each of the three C's are discussed in the following sections.

Curiosity

Groups have demonstrated behavioral outcome *a, critically observes surroundings to recognize opportunity*, by examining market trends, predicted market growth and sales, analyzing customer complaints through customer reviews of products, soliciting the Voice of Customer through customer interviews and surveys, and observing current events. For example, one group identified the opportunity to teach toddlers to properly wash their hands at daycare centers amid the COVID-19 pandemic and designed the Wally the Washing Wizard toy. Groups like this have also demonstrated behavioral outcome *e, observes trends about the changing world with a future-focused orientation/perspective*. As another example, a group learned through a qualitative study about parents' experiences of toothbrushing with children that was published in JDR Clinical & Translational Research in 2016, a journal from the International Association of Dental Health, that dental caries was one of the most prevalent diseases that is preventable through parent supervised brushing (PSB), however, parents experienced difficulties with PSB due to the environmental context of stressful lives and other barriers. This group recognized the opportunity to facilitate or help the parents with PSB and came up with the Smiling Giraffe toy that teaches children how to properly brush their teeth in a fun way.

Behavioral outcome *c, gathers data to support and refute ideas*, was demonstrated in a variety of ways including gathering customer reviews data, soliciting Voice of Customer, reviewing published data, examining market shares, sales, price points, and revenue of similar products, evaluating education standards and child development theories, etc. Those groups that solicited Voice of Customer have also demonstrated behavioral outcome *f, collects feedback and data from many customers and customer segments*. For example, one group examined toy safety issues around the use of paint that contains lead, by reviewing peer-reviewed publications, CDC (Centers for Disease Control and Prevention) guidelines, and Consumer Product Safety Commission (CPSC) regulations and avoided paint in their final product. As another example, a group collected 34 responses from potential customers. This group used pie and bar charts to

show the responses and used insights gained from these responses to make decisions (Fig. 1 shows an example of such charts).

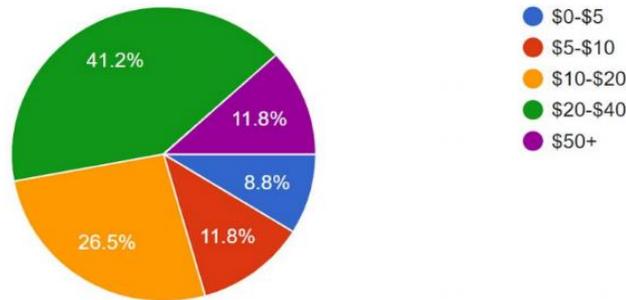


Fig. 1. Customer survey response for the question, ‘How much do you usually spend on a new toy?’ from one of the group’s proposal document

Another group noted the following that supported their decision to design a STEM focused toy:

“In 2016 STEM associated toys accounted for 27.5% of the \$82 billion global toy industry, and this category of toys has grown by approximately 5% each year since 2010 (Rumbaugh, 2018).”

Yet another group investigated the popularity of different genres of sensory toys for children with Autism to help inform their decisions:

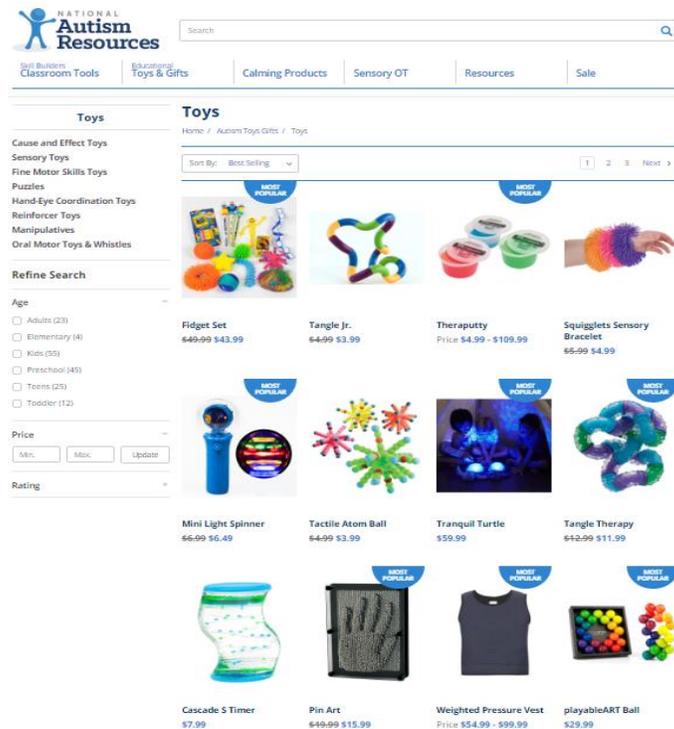


Fig. 2. Best-selling educational toys for children with Autism from one of the group’s proposal document

Behavioral outcome *d*, *suspends initial judgement on new ideas*, was demonstrated when groups examined multiple ideas and provided rationale to justify why an idea was more effective than the others. For example, a group used SWOT analyses to evaluate their ideas' strengths, weaknesses, opportunities, and threats, and used insights gained from their SWOT analyses to judge the ideas.

Creation of Value

Groups demonstrated behavioral outcome *i*, *focuses on understanding the value proposition of a discovery*, through the discussions of value creation for both the fictional company and the potential customers. For example, many of the groups discussed value creation for the fictional company from an economic point of view, by analyzing and predicting the profit potential of their design. Many of the groups also discussed how their design adds value for their potential customers.

The groups that demonstrated behavioral outcome *j*, *describes how a discovery could be scaled and/or sustained, using elements such as revenue streams, key partners, costs, and key resources*, by discussing mass production considerations, manufacturing methods, maintenance issues, assembly, labor costs, product packaging, etc. For example, one group performed a break-even analysis that considered costs for materials, marketing, labor, insurance, etc. and fees, and demonstrated the financial feasibility of their design in the long term.

The one group that demonstrated behavioral outcome *l*, *engages in actions with the understanding that they have the potential to lead to both gains or losses*, performed a SWOT analysis to show their idea's strengths, weaknesses, opportunities, and threats.

Connections

Behavioral outcome *n*, *persuades why a discovery adds value from multiple perspectives (technological, societal, financial, environmental, etc.)*, was demonstrated by groups when they discussed how their design adds value for the fictional company and/or the potential customers from at least two different perspectives, such as technological, economic, social, educational, and environmental. Most groups demonstrated this outcome through the discussions of value creation from the economic perspective for the fictional company and the social and/or educational perspective for the potential customers. Those groups that discussed value creation for the fictional company from an economic standpoint either discussed profits and/or performed financial analysis (e.g., determined Return on Investment, ROI, or break-even point). And those who discussed value creation for potential customers from a social/educational point of view

mentioned how their design would benefit these potential customers, for example, their design would help a specific group of children develop cognitively. For example, one group discussed:

“When it comes to the educational value of our design, it helps tangibly hit educational standards laid out in the [State] Early Learning Standards. For example, it helps with the children’s attentiveness, because it requires continued efforts from the children when playing. It also helps develop the children’s mathematical skills, such as counting and geometry. It helps with inquiry and application as it requires the children to use objects as intended, makes things happen and watches for results or repeats action. Furthermore, it promotes physical health and development, more specifically, fine motor development.”

The groups that have demonstrated behavioral outcome *q*, *integrates/synthesizes different kinds of knowledge*, have integrated technological knowledge as well as knowledge from child/cognitive development theory, social science, human anatomy, occupational therapy, market analysis, financial analysis, regulations, standards, etc. in their design process. For example, one of the groups mentioned:

“According to Rookie Parenting, in an article written in 2017, at age 3 children start to develop their Pre-Frontal Cortex. This allows them to start making sense of how the world works. This is also the time where their brain is developing rapidly. This is the exact time parents want to start introducing their children to science and new ideas. At ages 4-5 children are gaining more self-recognition which allows them to tinker with and memorize more functions on their own, which allows them a better understanding of a mechanical design. Also at ages 4-5 children develop a longer attention span allowing them to play with toys for a longer period of time, so a design with visible mechanisms allows them to explore and watch as the toy works. Finally, children at this age can only identify four colors and three shapes on average according to Ages & Stages – Four Year Olds & Five Year Olds, thus, a design that includes no more than five colors and four shapes will help kids of this age to gain confidence.”

Overall, the project has achieved the outcome of fostering the development of an entrepreneurial mindset. It provided opportunities for students to exercise their curiosity, gather different kinds of information and make connections and integrate the information throughout the design process, and focus on the value creation of their design. Through this project, student groups have demonstrated entrepreneurial mindset behavioral outcomes in a variety of ways.

Summary

In summary, a hands-on design project has been implemented in a junior level mechanical engineering course, Mechanism Design and Analysis, which not only focuses on developing and practicing technical skills but also fostering the development of an entrepreneurial mindset. The

open-ended group design project involves the investigation of the toy market, identification of an opportunity, and the design and prototyping of a mechanical toy that fulfills the opportunity identified. The ways in which student groups have demonstrated KEEN's three C's, *curiosity*, *connections*, and *creation of value*, were investigated through the analysis of project proposal documents from three offerings of the course. More specifically, the number of student groups that demonstrated each of the 17 entrepreneurial mindset behavioral outcomes and ways in which they demonstrated them were determined.

It was found that all groups from all three offerings of the course have demonstrated at least one behavioral outcome for *each* of the three C's. More than 85% of the groups have demonstrated at least one other behavioral outcome for *each* of the three C's. And more than 70% of the groups have demonstrated one other behavioral outcome for *curiosity*. The groups demonstrated each of the entrepreneurial mindset behavioral outcomes in multiple ways and specific examples of ways in which they demonstrated these outcomes were shared and discussed.

In conclusion, the open-ended hands-on toy design project implemented in the Mechanism Design and Analysis course has helped majority of the students exercise their curiosity in three different ways (i.e., demonstrating three entrepreneurial mindset behavioral outcomes for *curiosity*), helped them make connections and integrate different kinds of information in two different ways (i.e., demonstrating two entrepreneurial mindset behavioral outcomes for *connections*), and provided opportunities for them to focus on and understand value creation of their design in at least two different ways (i.e., demonstrating three entrepreneurial mindset behavioral outcomes for *creation of value*).

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