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《为了以工程为着重点建设一个流线型的、紧密结合的、最有效率的中小学科学技术工程数学课程的模式的建议书》（Proposed Model for a Streamlined, Cohesive, and Optimized K-12 STEM Curriculum with a Focus on Engineering）

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原文为英文，并由原作者翻译为中文。
为了中文表意的流畅，作者在不违反原文意思的前提下，做了少量“技术性”修补。

Abstract

This article presents a proposed model for a clear description of K-12 age-possible engineering knowledge content, in terms of the selection of analytic principles and predictive skills for various grades, based on the mastery of mathematics and science pre-requisites, as mandated by national or state performance standards; and a streamlined, cohesive, and optimized K-12 engineering curriculum, in terms of a continuous educational process that starts at kindergarten and/or elementary schools, intensifies at middle schools, differentiates at high schools and streamlines into four-year universities through two-year community colleges, integrating solid mastery of particular analytic skills and generic engineering design processes. This article is based upon a "Vision Paper" that was presented at the International Technology Education Association's 71st Annual Conference held in Louisville, Kentucky under the sponsorship of Dr. John Mativo, from the University of Georgia. It is hoped that many ideas explored in this article could provide answers to the problems in the current practice of K-12 engineering education, as discussed in the authoritative report issued several months later, on September 8, 2009, by the Committee on K-12 Engineering Education established by the National Academy of Engineering and the National Research Council, titled *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, which included the absence of cohesive K-12 engineering curriculum and the lack of well-developed standards.

摘要

这篇文章根据对全国以及州政府的规定的学业表现标准（performance standards）预设要求的（pre-requisites）数学运算技能和科学知识的掌握程度，提出了一个清晰地描述在选择分析原则和预测性技能方面、各个年级的中小学生的年龄上可能学习的工程知识内容的模式；以及一种流线型的、紧密结合的、最有效率的中小学科学、技术、工程、数学课程，依据一种从幼儿园抑或小学开始、在初中得到加强、在高中分科、通过二年制社区学院流线型地融入四年制大学、并且把对于特定的分析性机能的牢固的掌握同通用性的工程设计程序相结合的连贯的学习过程。这篇文章是建立在一个曾经在佐治亚大学（the University of Georgia）约翰·马提伏博士（Dr. John Mativo）的赞助下在肯塔基州路易斯维尔市（Louisville, Kentucky）举办的国际技术教育协会第71届年会（International Technology Education Association's 71st Annual Conference）上发表过的"远景规划论文"的基础上的。希望这篇文章中所探索过的许多意见可以提供一些答案，帮助解决许多个月之后、在2009年9月8日由全国工程学院（The National Academy of Engineering）和全国研究理事会（The National Research Council）所联合设立的中小学工程教育委员会（The Committee on K-12 Engineering Education）发表的、题为*《中小学工程教育：理解现状和改善前景》（Engineering in K-12 Education: Understanding the Status and Improving the Prospects）*的权威性的报告里所讨论的、目前中小学工程教育的实践中所存在的问题，其中包括连贯性的中小学工程课程体系不存在、和缺乏发展健全的教学标准。

Introduction

In the last decade, it has been perceived by scholars and administrators involved with K-12 STEM education as well as concerned business leaders that the shortage of engineering graduates from U.S. colleges must be resolved. In fact, the numbers of engineering degrees awarded over the last 20 years by U. S. universities was quite small. The National Science Foundation Statistics (2008) indicated that, in the years 1985 - 2005, the number of earned bachelor's degrees ranged from approximately 60,000 to 80,000; the number of earned master's degrees ranged from approximately 20,000 to 34,000; and the number of earned doctorate degrees ranged from approximately 3,700 to 6,000. Wicklein (2006, p. 29) indicated that in the United States, "currently, engineering education has close to a 50% attrition rate for students. […] Georgia currently seeks 50% of the engineering workforce from out-of-state sources." In an effort to solve this problem, K-12 schools across the United States have begun to incorporate engineering design into technology education curriculum. Hill (2006) indicated that "initiatives to integrate engineering design within the field of technology education are increasingly evident." Smith (2007, pp. 2-3) affirmed the achievements made so far throughout U.S. high schools by noting, "the integration of engineering design into secondary technology education classes," but also indicated that the "fragmented focus and lack of a clear curriculum framework" had been "detrimental to the potential of the field and have hindered efforts aimed at achieving the stated goals of technological literacy for all students." An authoritative report issued on September 8, 2009, by the Committee on K-12 Engineering Education established by the National Academy of Engineering and the National

引言

在最近的十多年中，同中小学科学、技术、工程和数学教育（K-12 STEM education）有关的学者们和行政官员们、以及关注这个领域的工商界领袖们觉察到，美国大学中工程专业毕业生缺少的问题必须解决。事实上，在过去的20年当中，美国大学中获得工程学位的学生数量是相当少的。全国科学基金会2008年统计（The National Science Foundation Statistics 2008）表明，在1985年到2005年间，获得学士学位的人数大约在60,000人到80,000人之间徘徊；获得硕士学位的人数大约在20,000人到34,000人之间徘徊；获得博士学位的数量大约在3,700人到6,000人之间徘徊。魏克兰（Wicklein，2006年，第29页）指出在美国，“目前，工程教育有着将近50%的学生退学率。[…] 佐治亚州目前从本州之外的源流中招聘50%的工程专业工作者”。在解决这个问题的努力中，美国各地中小学校已经开始把工程设计纳入技术教育课程。希尔（Hill，2006年）指出“把工程设计纳入技术教育课程领域的提议越来越明显”。斯密斯（2007年，第2至3页）在提到“把工程设计纳入中学技术教育课程”时肯定了美国各地高中至今所取得的成就，但是也指出“支离破碎的焦点”和“缺乏清晰的课程设置的框架”已经成为“发挥这个领域的潜在能量的不利因素，并且已经阻碍了为达到已经宣示过的所有学生都掌握技术技能（technological literacy for all students）的目标所做的努力”。在2009年9月8日由全国工程学院（The National Academy of Engineering）和全国研究理事会（The National Research Council）所联合设立的中小学工程教育委

Research Council, titled Engineering in *K-12 Education: Understanding the Status and Improving the Prospects*, confirmed the existence of similar problems in the current K-12 engineering curriculum. To be more specific, the most serious problems in K-12 engineering education explored in the report by the Committee on K-12 Engineering Education (2009) include (a) absence of cohesive K-12 engineering curriculum ("Engineering design, the central activity of engineering, is predominant in most K-12 curricular and professional development programs. The treatment of key ideas in engineering, many closely related to engineering design, is much more uneven;" pp. 7-8; p. 151); and (b) lack of well developed standards ("the teaching of engineering in elementary and secondaryschools is still very much a work in progress . . . no national or state-level assessments of student accomplishment have been developed;" p. 2). During the International Technology Education Association's 71st Annual Conference, and under the sponsorship of Dr. John Mativo, from the University of Georgia, this author presented a proposed model for:

• A Clear Description of K-12 Age-Appropriate Engineering Knowledge Content: Selection of K-12 age-appropriate engineering analytic principles and predictive skills for various grade levels should be based on the mastery of mathematics and science (notably physics and chemistry) prerequisites, as mandated by national or state performance standards for previous or same grade levels.

员会（The Committee on K-12 Engineering Education）发表的、题为*《中小学工程教育：理解现状和改善前景》（Engineering in K-12 Education: Understanding the Status and Improving the Prospects）*的权威性报告证实了目前的中小学工程课程中类似问题的存在。说得更加具体一些，中小学工程教育委员会（The Committee on K-12 Engineering Education，2009年）发表的报告中所探讨的中小学工程教育中所存在的最严重的问题包括（a）中小学工程课程缺乏整体性（"工程设计作为工程活动的中心，在大多数中小学课程和专业发展项目中占有优势地位。对于关键的工程概念 - 其中的许多是同工程设计紧密相关的 - 的处理，则非常非常地更不平衡"，第7至8页，第151页）；（b）缺乏发展健全的标准（"在中小学校教授工程课程仍然在很大程度上是一项正在进行的工作…还没有发展出全国的或州一级的评估学生成绩的标准"（第2页）。本文作者曾经在佐治亚大学（The University of Georgia）约翰•马提伏博士（Dr. John Mativo）的赞助下，在国际技术教育协会第71届年会（International Technology Education Association's 71st Annual Conference）上提出了一个模式，用来解决如下问题：

- 一个对于适合中小学校学生年龄的工程知识内容的清晰的描述：在为各个年级的学生选择适合中小学校学生年龄的工程分析原理和预测性技能（engineering analytic principles and predictive skills）的时候，必须以对作为先决条件（prerequisites）的数学技能和科学（尤其是物理和化学）知识的掌握为基础，正如全国的和州一级的对于前一个或目前的年级所规定的成绩表现的标准所要求的那样。

• A Streamlined, Cohesive, and Optimized K-12 Engineering Curriculum: A cohesive and continuous educational process that starts at kindergarten and elementary schools, intensifies at middle schools, differentiates at high schools, and streamlines into four-year universities through two year community colleges could be a solution to various problems in U. S. engineering education. This principle of streamlining could also apply to various fields of STEM (see Figures 1 and 2). The optimization of K-12 engineering education could be achieved through (a) the integration of particular analytic and predictive principles and skills, with different modes of generic engineering design process, both transferable to collegiate engineering studies and (b) the integration of traditional formula-based analytic computations and physical laboratory experiments with modern digital simulation technology. The proposed curriculum is intended to seamlessly link K-12 engineering and technology curricula to university engineering programs, by making engineering knowledge content learned at K-12 schools transferable to engineering courses taught at the university level; this is the “missing E” (engineering) that has been neglected by existing models of K-12 STEM curricula.

This proposed model might contribute to the solution of the problems described in the report by the Committee on K-12 Engineering Education (2009).

Proposed Model for a Clear Description of K-12 Age-Appropriate Engineering Knowledge Content

• 一个流线型的、紧密结合的、最有效率的中小学科学技术工程数学课程的模式：这是一个紧密结合的、连贯性的教育过程，从幼儿园和小学开始，在初中得到加强，在高中实行分科，并且通过二年制社区学院，流线型地融入四年制大学，可以为美国工程教育中存在的许多问题提供解决方案。这个流线型教育过程的原则同样地可以适用于科学、技术、工程、和数学（STEM）的各个不同的领域（参见图1和图2）。取得中小学工程教育的效益的最大化的途径包括（a）把特殊的分析性和预测性原理和技能与通用的工程设计过程的各种不同的模式相结合，使这两者都可以同大学里的工程教育相融合，（b）把传统的以解题公式为基础的分析性的计算和实体的实验室试验活动同现代的数码模拟技术相结合。本文作者所建议的课程设置的宗旨是，通过让中小学校里学到的工程知识内容可以在大学一级的工程课程所应用，把中小学工程技术教育课程同大学工程教育课程天衣无缝地衔接起来；这就是现存的中小学科学、技术、工程、和数学（STEM）课程设置的各种模式中被忽视的“缺失的E字母”（即engineering，或“工程”）。

本文提出的模式可能对于中小学工程教育委员会（The Committee on K-12 Engineering Education）报告（2009年）所描述的各种问题的解决做出贡献。

为了清晰地描述适合中小学校学生年龄的工程知识内容所提出来的一个模式

The key to understanding how to scientifically, rationally, and effectively infuse engineering analytic content knowledge and the design process into K-12 curriculum can be related to the understanding of the following four basic types of relations:

理解如何科学地、理性地、和有效地把工程分析的知识内容和设计过程注入中小学校的课程设置的关键，是同对于如下四种基本关系的理解相关联的：

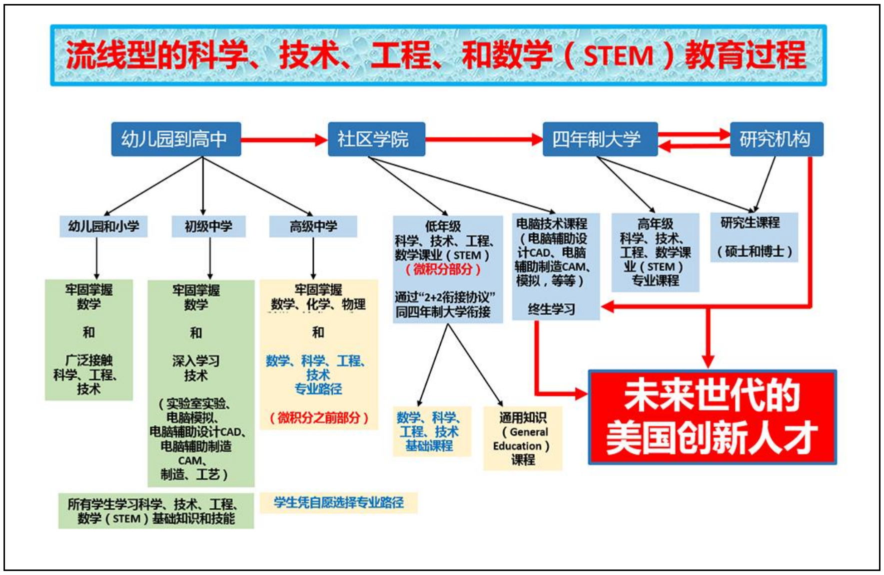

图 1.一个流线型的、终生的科学技术、工程、和数学（STEM）教育的远景设想。

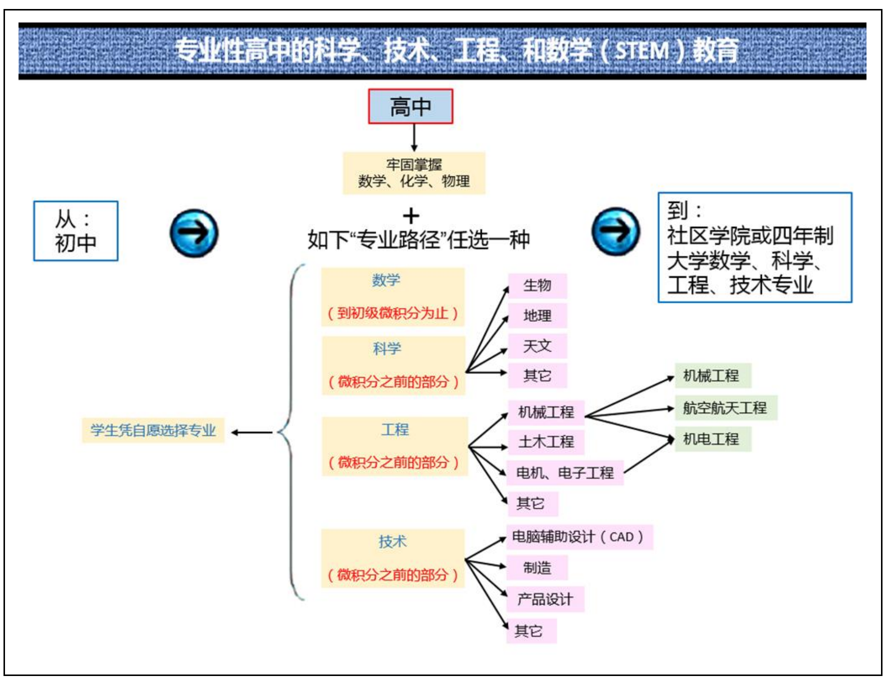

图 2.一个流线型的科学、技术、工程、和数学（STEM）教育模式。

(1) Relations among mathematics, science, engineering, and technology: Mathematics provides computational tools for the predictive analysis in sciences, engineering, and technology; it is the primary gatekeeper for the inclusion or noninclusion of any science, engineering, or technology topic into any course taught at any grade level. Sciences (physics, chemistry, biology, etc.) are concerned with discovery and delivery of knowledge, and they form the foundation for engineering and technology; additionally, sciences (notably physics and chemistry) constitute the secondary gatekeeping determinants. Engineers apply knowledge gained through the scientific process in the creative design of products and systems to be used in solving everyday problems, and they are the vital link in the STEM system that transforms "pure" knowledge into usable and financially profitable assets (products and systems), through the process of innovation. Technology is the skills of applying, maintaining, and arranging products and systems in the solution of daily problems. Based on this understanding, the selection of engineering topics for any grade level must be based on the prior mastery of prerequisite principles and skills in mathematics and science courses.

(2) Relations between specific engineering analytic knowledge content and the generic engineering design process: Mastery of a sufficient amount of specific analytic knowledge content (principles, concepts, computational skills using formulas or simulation software, as well as experimental and research methods) constitutes the foundation for meaningful engineering design; in contrast, engineering design gives students an opportunity to synthesize knowledge and skills gained from various branches of engineering into workable solutions that help create and maintain usable products and systems. Based on this

（1）数学、科学、工程、和技术之间的关系：数学为在科学、工程、和技术方面进行预测性的分析提供计算的工具；这是决定能不能将任何的科学、工程、和技术的课题注入在任何年级教授的任何课程的主要的"门卫"。科学（物理、化学、生物学，等等）所关注的是发现和传输知识；它们构成了工程和技术的基础；除此之外，科学（尤其是物理和化学）构成了二级的"门卫"式的决定因素。工程师们把通过科学研究过程获得的知识应用在创意性的产品和系统设计中，以便解决日常生活中所碰到的各种问题；他们并且是科学、技术、工程、和数学（STEM）体系中，通过创新的过程，把"纯粹的"知识转化为有用的、并且在财务上可以盈利的资产（产品和系统）的重要的环节。技术是应用、维护、和安排产品和系统，以便解决日常生活中所碰到的各种问题的技能。基于这样的理解，为任何年级的学生选择工程课题，都必须建立在预先掌握了数学和物理课程中所学习的必要的原理和技能的基础上。

（2）特定的工程分析的知识内容同通用的工程设计过程之间的关系：掌握足够数量的特定的工程分析的知识内容（原理、概念、使用公式和电脑模拟软件的计算技能、以及实验和研究方法），构成了有意义的工程设计的基础；相比之下，工程设计为学生提供综合运用在各种专业的工程课程中所学到的知识和技能、找到切实可行的解决方案、创造和维护有用的产品和系统的机会。基于这样的理解，要把工程

understanding, the inclusion of engineering as a meaningful K-12 subject must be based on an appropriate balance between instruction of specific engineering analytic knowledge content and the inculcation of the ability of using engineering design processes.

(3) Relations between different modes of design and different stages of K-12 students' cognitive developmental level: Design processes could include different modes.

- Creative and Conceptual Design: Examples of this mode include conceptual imagination, ideation for simple product and tools (e.g., everyday items, such as shopping bags, benches, chairs, tables). Kindergarten and elementary school students are good at wild imagination with little training, but at this age they are just beginning to learn basic mathematics and sciences; thus, this mode could be used in Grades K-5.

- Technology Education Design: This mode of design is based on "trial-and-error" or "hypothesis-and-testing" experiments; and it is an important method of scientific inquiry. An example of this mode could be the design, fabrication, and testing of composite materials, based on a rational hypothesis and its proof or disproof through experiments. This mode could be used in Grades 6-8.

- Analytic Reduction: This mode is good for solving well-structured, simple, and usually closed-ended engineering design problems (e.g., designing a gear set that changes speed and direction of rotational motions) that are focused on scientific and technological issues. It is suitable for stand-

作为一种有意义的科目纳入中小学课程，就必须把它建立在一种在教授特定的工程分析知识内容同培养使用工程设计过程的能力之间维持适当的平衡的基础上。

（3）不同的设计模式和中小学学生的智力发育的不同阶段之间的关系：设计过程可以包括下列不同的模式。

- 创意性和概念性的设计（Creative and Conceptual Design）：这种模式的例子包括概念性的想象（conceptual imagination）、构思（ideation）简单的产品和工具（例如，日用物件，比如购物袋、长凳子、椅子、和桌子）。幼儿园和小学学生只要稍微训练一下就能够具备良好的狂野的想象能力，但是在这个年龄阶段，他们刚刚开始学习基础的数学和科学知识；因此，这个模式可以在幼儿园到小学第五年级运用。

- 技术教育设计（Technology Education Design）：这一种设计模式是建立在"反复试验"的"试错法"（trial-and-error）、或叫作"假设和求证"（hypothesis-and-testing）的基础上的；这是科学探索中的一种重要的方法。这种模式的一个可能的例子是，根据一种理性的假设并且通过试验验证或否定假设，设计、制作、和试验一些复合材料。这种模式可以在中小学校第六年级到第八年级使用。

- 解析约简（Analytic Reduction）：这种模式对于解决结构良好的、简单的、在通常情况下属于封闭型的（closed-ended）工程设计问题而言是一种好模式（比如说，设计一组用来改变速度和旋转运动的方向的齿轮，这种设计所要着重解决的是各种科学技术问题）。它适合于涉及特别的成套的知识内容、独立设置的工程基础课或特定的专业课。这种模式

alone engineering foundation or specialty courses that deal with particular sets of knowledge content. This mode could be used in Grades 9-11.

- Systems Thinking: This mode of design is good for solving ill-structured, openended, and complex engineering design problems, which involve not only many branches of science and engineering, but also social studies (culture and economics), ecology and arts. It generally could lead to multiple results that satisfy the original design requirements. This is the most frequently used mode in real-world engineering design practice. Examples of this mode include senior-year design projects in any typical university undergraduate engineering program. This mode would be most suitable for Grade 12 or graduation year “capstone” design courses, and it could be used for extracurricular interdisciplinary design projects throughout Grades K-12.

Engaging K-12 students in the design process is feasible. Previous research conducted by Fleer (2000) and funded by the University of Canberra and the Curriculum Corporation of Australia for the development of a technology curriculum concluded that children as young as 3 to 5 years of age can engage in oral and visual planning as part of the process of making things from materials; their planning involved the use of lists and designs of what they intended to make. Claxton, Pannells, and Rhoads (2005) indicated that the level of developmental maturity occurred around 5 to 6 years of age; that a creative peak occurred at 10 to 11 years old; and that “after age 12, a gradual but steady rise in creativity occurred through the rest of adolescence until a second peak was reached around 16 years of age” (p. 328).

可以在中小学校第九年级到第十一年级使用。

- 系统思维（Systems Thinking）：这种设计模式对于解决结构不良的、开放型的、复杂的、涉及到不仅仅好多个门类的科学和工程知识、而且还涉及到许多社会科学领域如文化与经济、环境保护、和艺术的工程设计问题而言是一种好模式。它一般来说可能导向产生可以满足最初的设计要求的多种结果。这是现实世界里的工程设计中最常使用的模式。这种模式的例子包括许多典型的大学本科工程专业的高年级设计项目。对于中小学校第十二年级或毕业年级的“压顶石”（capstone）设计课程来说，这种模式将是最合适的模式；不仅如此，它可以用于中小学校所有年级的课外的、跨科系的设计作业。

让中小学生加入设计过程是可行的。以前由福利尔（Fleer， 2000年）在堪培拉大学（The University of Canberra）和澳大利亚课程开发公司（The Curriculum Corporation of Australia）资助下为了开发一项技术课程所做的研究得出结论，认为幼小到三岁到五岁的儿童也可以进行口头的或者视觉的计划，作为利用原材料制作物件的过程的一部分；他们所做的计划涉及到使用列表和设计他们想要制作的东西。克雷克斯顿（Claxton）、帕内尔斯（Pannells）、和若德斯（Rhoads，2005年）指出达到发育成熟的水平发生在五岁到六岁的年龄之间；创新能力的高峰（creative peak）发生在十岁到十一岁的年龄之间；“在十二岁之后，创新能力的逐渐的但是稳定的上升发生在整个成年期间，直到在大约十六岁的年龄达到第二次高峰”（第328页）。

(4) Relations between kindergarten/elementary education and secondary education: Throughout the Grades K-6, students barely learn the basics of STEM, English language, and other mandated subjects; they have a very limited set of mathematics skills to carry out engineering analysis and prediction-related computations; thus, an integrative STEM approach in general science courses, with broad exposure to a variety of science, engineering, and technology subjects, would be very age-appropriate. At the secondary level, students either have mastered or are in the process of mastering more in-depth and specialized mathematics skills (algebra, geometry, trigonometry), and they have mastered basic scientific principles that are needed for understanding engineering analytic principles; thus, more extensive engineering studies could be implemented; here, depth and specialty should be emphasized.

（4）幼儿园与小学教育同中学教育之间的关系：贯穿整个幼儿园到小学六年级期间，学童们刚刚开始学习科学、技术、工程、和数学（STEM）、英语、以及其它规定必修的课程的基础知识和技能；他们的数学技能非常有限，不足于进行工程分析和同预测有关的计算；因此，在一般科学课程中，提供一种综合性的科学、技术、工程、和数学（STEM）学习过程，广泛地接触各种各样的科学、工程、和技术课题，将是非常适合学童年龄的。在中学阶段，学生要么已经掌握了或者处于正在掌握更加深入的、特殊的数学技能（代数、几何、三角），并且已经掌握了一些为理解工程分析的原理所需要的基本的科学原理；因此，更加广泛地学习工程课题是切实可行的；在这里，可以强调深度和专业性。

Method for the Selection of K-12 Age-Appropriate Analytic Principles and Skills

选择适合中小学年龄的分析性原理和技能的方法

Up to this date, “hard-core” engineering content from various subjects, such as statics, dynamics, and fluid mechanics, are generally not systematically taught until students enroll in university undergraduate courses; however, textbooks used in these courses could be analyzed to determine the mathematics and science (notably physics and chemistry) prerequisites for various topics covered therein. Topics whose prerequisites are covered at various K-12 grade levels could be selected for pedagogic experiments at higher grade levels, to determine their age-appropriateness. This author’s research on high school age-appropriate statics and fluid mechanics topics, during Spring 2009, at the University of Georgia, incorporated the following steps:

至今为止，各种工程课程中的“硬件核心”（hard-core）内容，例如静力学、动力学、流体力学，一般来说，直到进入大学本科课程，并没有系统性地教授给学生。尽管如此，这类课程中所使用的课本，可以拿来分析，以便确定其中所包含的各种课题对于预先掌握数学和科学（尤其是物理和化学）技能的要求。这些技能只要已经在中小学的各个年级预先掌握，有关的工程课题就可以选择在更高的年级进行教学试验，以便确定它们是否适合某个年龄。本文作者曾经在 2009 年春季学期在佐治亚大学（The University of Georgia），进行对于适合高中学生的静力学和流体力学课题的研究，使用了如下步骤：

(1) Select textbooks and instructor solution manuals that are among the most popular for undergraduate engineering statics and fluid mechanics courses;

(2) Read carefully every paragraph in the body text to find and record the prerequisite science knowledge content needed for each topic (notably physics and chemistry);

(3) Find the relevant computational formulas to determine and record the mathematics skills needed; and

(4) Compare the recorded data with the mandates of the Performance Standards for Mathematics and Sciences of the Department of Education of a selected state, to determine the grade level for the inclusion of the topic.

This previous research indicated that, using the mandates of the Performance Standards for Mathematics and Sciences of one of the "low performing" states in the United States, around 50% of all topics in the textbooks used in undergraduate statics and fluid mechanics courses are based on precalculus mathematics skills and on scientific principles that are covered prior to 9th grade, and therefore, could be taught to 9th Grade high school students. For other foundation engineering courses common to all undergraduate programs, such as dynamics, strength of materials and material science, heat transfer, thermodynamics, engineering economics, and aerodynamics, the percentage figure ranges from 30% to 50% based on this author's rough estimates using similar standards.

Even though high school students could learn engineering topics, this does not automatically mean that they would have enough energy to proceed. Due to many factors, K-12 schedules are crowded with many mandated subjects; and the academic resources for implementing engineering

（1）选择在大学本科工程系静力学和流体力学课程中最受欢迎的课本和教师解题手册；

（2）认真阅读正文文本中的每一个段落，以便找出并且记录学习每个课题前必须预先掌握的科学知识内容（尤其是物理和化学）；

（3）找出相关的计算公式，以便确定并且记录所需要的数学技能；并且

（4）把记录过的信息同选定的一个州政府的《教育厅数学与科学学业表现标准》（Performance Standards for Mathematics and Sciences of the Department of Education）规定相比较，以便确定把这个课题纳入哪一个年级。

以前做过的这个研究表明，使用美国国内"学业表现低"（low performing）的州当中的一个的州政府《教育厅数学与科学学业表现标准》中的规定，大学本科静力学和流体力学课程所使用的教科书中的全部课题当中，大约50%是建立在中学九年级之前已经学完的微积分以下的数学技能和科学原理的基础上的；因此，它们可以教授给九年级的学生。对于其它大学本科专业通用的工程基础课程（如动力学、材料力学、材料科学、传热学、热力学、工程经济学、和空气动力学）而言，按照本文作者使用同样的标准所作的粗略估计，这个百分比的数值在30%至50%之间。

尽管高中学生有可能学习工程课题，这并不自动地意味着他们将有足够的精力投放其中。因为许多因素，中小学课程表已经塞满了许多规定的必修课；并且用来推行

curriculum are rather limited. Thus, realistically only the most important engineering analytic content knowledge can be attempted to be infused in the curriculum. Expert opinions of the relative importance of various topics can be collected, possibly through a five-point Likert scale, four-round Delphi survey. This survey could be used to determine the relative importance of various engineering analytic principles and computational skills for inclusion into a potentially viable K-12 engineering curriculum and eventually to establish a set of national or state K-12 engineering performance standards.

工程教育的教学资源是相当有限的。因此，说实在的，只有最重要的工程分析的知识内容，能够被尝试纳入课程中。有关各种不同的课题的相对的重要性的专家意见，有可能通过“五点里克特量表”（Five-point Likert Scale）和 “四轮德尔菲调查”（Four-round Delphi Survey）来收集。这种调查可以用来确定各种不同的工程分析原理和计算技能的相对的重要性，以便纳入一种切实可行的中小学工程课程，并且最终建立全国的、或者各州的中小学工程课程教学标准。

Proposed Model for a Streamlined, Cohesive, and Optimized K-12 Engineering Curriculum

Based on the above mechanism for the development of a clear description of K-12 age-appropriate engineering knowledge content, in this article the author proposes a new model for a streamlined, cohesive, logical, and optimized K-12 Engineering Curriculum, which could also be used as a general model for STEM, including mathematics and sciences (Figures 1 and 2). This new model could provide a workable framework for organizing and sequencing the essential knowledge and skills to be developed through K-12 engineering education in a rigorous or systematic way, making the future K-12 Engineering curriculum optimally connected to college-level engineering programs and to real world practice, and eventually lead to the establishment of formal national and state learning standards or guidelines on K-12 Engineering Education.

关于一个流线型的、紧密结合的、最有效率的中小学工程课程的模式的建议

以上述的用来发展一个清晰地描述适合中小学学生年龄的工程知识内容的机制为基础，作者謹在本文中建议采用一种流线型的、紧密结合的、合乎逻辑的、最有效率的中小学工程课程的新模式，它同样地可以作为一种通用的模式应用在包括数学和科学在内的理科（STEM）领域（如图1和图2所示）。这个新的模式可以提供一种切实可行的框架，用于把贯穿整个中小学工程教育的必须修习的基本知识和技能强有力地、系统地组织起来并且编列先后次序，让未来的中小学工程课程最大限度地同大学水平的工程教育、以及现实世界中的实践衔接起来，并且最终导致建立起正式的全国和各州的中小学工程教育的教学标准（learning standards）、或指导方针（guidelines）。

The Proposed Model would include two components: a Regular Curriculum (Table 1) for all students enrolled in K-12 Engineering Curriculum or “Career Pathways,” and an Extracurricular Enrichment Program for selected groups of students.

First Component - Regular Curriculum

Lewis (2007) indicated that, “to become more entrenched in schools, engineering education will have to take on the features of a school subject and argued in terms of what is good for children” (p. 846). In addition, Lewis (2007) discussed the need to (a) establish a “codified body of knowledge that can be ordered and articulated across the grades” with focused attempt to systematize the state of the art in engineering in a way that is translatable in schools (instead of short term efforts focused on a particular topic or unit) and (b) make engineering education a coherent system with the creation of content standards for the subject area, in line with science and technology education (pp. 846-848).

As shown in Table 1, the Regular Curriculum is designed for all students who are interested in STEM Career Pathways and could be adequately trained in basic mathematics skills; it is aimed at implementing engineering design process stepby- step, progressing from simple to complex, from easy to difficult, from broad to deep, from generic to special, in an incremental, logical, systematic, and cohesive sequence. This is based on age-appropriateness, with a deep respect for time proven traditional pedagogy while

建议中的模式将包括两个组成部分：一个“正规课程”（Regular Curriculum，如表1所示）供所有在中小学工程课程（K-12 Engineering Curriculum）或“职业路径”（Career Pathways）注册的学生使用，和一个供入选的学生使用的“课外加强学习项目”（Extracurricular Enrichment Program）。

第一个组成部分 – 正规课程（Regular Curriculum）

路易斯（Lewis，2007 年）指出，“如果想要在学校里更加根深蒂固的话，工程教育就必须具备学校里的学科的各种特征，并且用对儿童有什么益处的话题争辩”（第 846 页）。除此之外，路易斯（Lewis，2007 年）探讨了如下需要：（a）建立一种“经过编纂整理的整体的知识体系（codified body），它可以贯穿所有年级排列次序并衔接”，并且集中地尝试把工程中的最新技术系统化、使它们能够在学校中可以转换（而不是在短时期内把努力的着重点放在某一个课题或单元），并且，（b）使工程教育变成一个紧密结合的整体，具备为学科的领域创制的教学内容的标准，如同科学和技术教育那样（第 846 至 848 页）。

如表 1 所示，正规课程（Regular Curriculum）是为所有的对科学、技术、工程、和数学职业路径（STEM Career Pathways）有兴趣的、并且能够在基础的数学技能方面得到充分的训练的学生所设计的；其宗旨是有步骤地实施工程设计程序，从简单的到复杂的、从容易的到困难的、从广泛的到深入的、从一般的到特殊的、渐进地、合乎逻辑地、有系统地、遵循紧密结合的序列向前推进。这样做是建立在适合学龄的、深度地尊重历经时间证明的传统的教学方法、同时吸收最近几十

incorporating the positive achievements of the recent decade in instructional technology, especially in terms of digital modeling and simulation technology. This curriculum is divided into several stages, each corresponding to the infusion of engineering design into a period of K-12 education: (a) kindergarten and elementary schools; (b) middle schools; (c) high schools; and (d) graduation year.

At Grades K-5 (kindergarten to elementary schools): All students would be introduced to science, engineering, and technology, while they built a solid foundation in mathematics. Students would be given an opportunity to: (a) have a broad exposure to diverse aspects of science, engineering and technology (the “breadth”); (b) foster ability of creative imagination (the “wild”); and (c) foster a systemic and holistic view of technological systems as interactive and interconnected. Students would master similar knowledge content that is traditionally required of college engineering and technology students in the following courses: Introduction to Science, Engineering and Technology; Engineering Ethics; and Appropriate Engineering and Technology. This stage would be similar to what many of U.S. K-12 schools have practiced during the past decade. Minimal modifications would be made regarding infusing age-appropriate engineering knowledge content through contextual, handson, and creative design activities.

At Grades 6-8 (middle schools): Courses included in this stage should be made available to all students and taken by all STEM-oriented students. During this stage, all students would consolidate their mathematics and science foundation and explore the basics of traditional and modern technology with more specialized and stand-alone courses. Students would master the fundamentals of modern technology that are

年间在教学技术上、尤其是在数码建模和模拟技术方面所取得的各种积极的成果。这种课程是分为几个阶段，每一个阶段同在某一个中小学教育的时期注入的工程设计相对应：（a）幼儿园和小学；（b）初中；（c）高中；和（d）高中毕业年级。

在第 K 年级到第 5 年级（幼儿园和小学）：所有的学生将入门学习科学、工程、和技术，同时建立牢固的数学基础。学生们将会有机会（a）广泛地接触各种不同领域的科学、工程、和技术（“广度”）；（b）培养创意性的想象能力（“野性”）；（c）培养把互动的、互相联系的各种技术体系有系统地、整体地观察的能力。在下列科目中，学生们将掌握某些与传统上大学工程和技术课程所要求的相同的知识内容：科学、工程和技术入门课；工程伦理课；以及合适的工程技术课。这个阶段将与过去十多年中美国许多中小学校的实践相类似。它在通过概念式的、动手的、和创意的设计活动，注入适合学龄的工程知识内容方面，将可能做出最小规模的修改。

在第6到第8年级（初中）：这个阶段所包括的课程必须对所有的学生开放，并且由所有有志于学习科学、技术、工程和数学的学生（STEM-oriented）修习。在这个阶段，所有的学生将巩固他们的数学和科学基础，并且通过更加专门的和独立的课程，探索传统和现代的技术的基础知识。

associated with engineering (e.g., CAD and 3D modeling, traditional and CNC manufacturing process, and others). This coursework would prepare them for a lifelong career related to STEM. For non-STEM-oriented students, technology courses included in this part of the Proposed Model could still help them to gain practical skills with lifelong benefits. The mathematics and science portions of this part of the Proposed Model would still be similar to what most of U.S. schools have practiced in the past, except that the content knowledge would be more specialized and intensive, including some relevant engineering topics, either as "word problems" or as mini research projects. In addition, specialized and intensive engineering- related technology courses would be offered.

学生们将掌握同工程有关的现代技术的基本知识和技能，如电脑辅助绘图（CAD）和立体建模。传统和电脑数值控制（CNC）的制造过程，等等。这类课业将为他们做好从事同科学、技术、工程和数学有关的终生职业做好准备。对于非科学、技术、工程和数学专业意向的学生而言，在本文所建议的模式中的这一部分所包括的技术课程，将仍然有可能帮助他们获得实用技能而终身获益。本文所建议的模式中的这一部分当中，数学和科学的部分，除了知识内容将变得更加专门和更加强化、纳入某些相关联的工程课题（作为"应用题"或袖珍研究项目作业），将仍然同美国大多数中小学校在过去所实行的相类似。除此之外，将提供专门的、加强的、同工程有关的技术课程。

At Grades 9-11 (high schools): Selective courses included in this stage should be taken by students enrolled in separate STEM Career Pathways; as shown in Figure 2, these Career Pathways could be any branches of science (biology, chemistry, physics, etc.), technology (CAD, manufacturing, product design, etc.), engineering (mechanical, civil, electrical and electronics, etc.), depending on changing national and local needs. During this stage, students would be branched out to different STEM "Career Pathways" of their choice, take a sequence of precalculus based, well-connected, and specialized courses. The specialized STEM "Career Pathways" would directly streamline students into relevant STEM majors at colleges or universities through cross-institutional transfer and/or articulation agreements, which might include

在第9到第11年级（高中）： 在分开的科学、技术、工程和数学职业路径（STEM Career Pathways）中注册的学生必须修习这个阶段所包括的选修课；如图2所示，这些"职业路径"，根据变化中的全国或各州的需要，可以是任何科系的科学（生物学、化学、物理职业路径等）、技术（电脑辅助绘图、制造、产品设计，等等）、工程（机械、土木、电机和电子，等等）。在这个阶段中，学生们将根据自己的选择分支到不同的科学、技术、工程、和数学"职业路径"（STEM "Career Pathways"）中，选修一系列以学习微积分前必修的数学课程（precalculus）为基础的、紧密联系的专业课程。专业的科学、技术、工程、和数学"职业路径"（STEM "Career Pathways"）课程将让学生们通过"跨机构的转学抑或衔接协议"（cross-institutional transfer and/or articulation agreement），直接地、流线型地融入两年制社区学院或四年制大学里相关的科学、技术、工程、和数学专业（STEM majors），这些协议可能将包括

dual high school and college credits (for technology courses such as engineering drafting and CAD/CAM) and the High School Certificate Examination in a particular area of STEM, for the completion of certain courses (such as Introduction to Science, Engineering, and Technology, Engineering Ethics, Appropriate Technology, etc.) or their precalculus portions. In the future, special examinations modeled after Fundamentals of Engineering (FE) could be designed to test the abilities of high school graduates to solve precalculus-level engineering problems. For students who pass these examinations, special accommodations could be granted (e.g., they would still be enrolled in undergraduate engineering courses to continue studying relevant topics beyond the precalculus portions they have learned at high schools, but they could be exempt from specific homework and quizzes related to precalculus portions, allowing them to devote their time to calculus-based course materials and to engineering design and research projects.

At Grade 12 (high school graduation year): The mathematics and science portions of this part of the Proposed Model would still be similar to what most U.S. schools have practiced during the past decade, leading to graduation from high school and entry into college education. In the last year of K-12 education, students enrolled in STEM “Career Pathways” would spend two semesters in a research or design “Capstone” project to demonstrate their ability to synthesize the knowledge content from various courses taken previously and to solve an open-ended real-world problem with reasonable complexity, in a “System Thinking” mode. This project could constitute the masterpiece of the students’ academic portfolio.

技术课程如工程绘图和电脑辅助设计与电脑辅助制造（CAD/CAM）的“高中与大学双重学分”（dual high school and college credits）、以及在某一个特定的科学、技术、工程、和数学专业领域的“高中考核证书”（High School Certificate Examination），证明已经完成了某些课程（如科学、工程和技术入门、工程伦理、适当的技术，等等）、或其中的微积分之前的部分。在未来，可以参照“工程基础考试”（Fundamentals of Engineering，缩写为FE）制定特殊的考试，以便考核高中毕业生的解决微积分之前的水平的（precalculus-level）工程问题的能力。对于通过了这类考试的学生，可以实行特殊的方便照顾措施，例如，他们仍然将在某些大学本科工程课程中注册，继续学习他们在高中还没有学到的、微积分之后的部分的相关的课题，但是，他们将被免除同微积分之前的部分课题有关的特定的作业和测验，允许他们把时间专门用在以微积分为基础的课程学习材料、和工程设计与研究项目上。

在第12年级（高中毕业年级）：本文中建议的模式当中的数学与科学的部分仍然将同美国大多数中小学校在过去的十数年间所施行的、让学生从高中毕业并且进入大学教育的政策相类似。在中小学教育的最后一年，在科学、技术、工程和数学“职业路径”（STEM “Career Pathways”）中注册的学生们将花费两个学期，完成一项研究课题或一种设计“顶石”（design “Capstone”）项目， 以便显示自己有能力把在以前完成的各种不同的课程中所学到的知识内容，以“系统思维”的模式（“System Thinking” mode），综合应用于解决一个开放性的、复杂程度合理的、现实世界中的实际问题。这个项目可以构成学生的“学术作品选集”（academic portfolio）当中的代表作（masterpiece）。

The instructors would advise, guide, and evaluate students, and they would teach additional topics relevant to the "Capstone" projects.

Core engineering concepts "go beyond tool skills… and beyond the digital skills that have captured the interest of the profession over the past two decades. Tools will change but even more important is the cognitive content and intellectual processes fundamental to effective technological problem solving and literacy" (Sanders, 2008, p. 6). The idea of a precalculus but "hard-core" high school engineering curriculum, the centerpiece of the Proposed Model is feasible. Most basic scientific principles and analytic skills related to engineering design that practical engineers work with on a regular basis are based on precalculus mathematics (trigonometry, algebra, geometry, and functions) with some needs for beginning calculus (integration and differentiation) and substantial needs for linear algebra. Traditionally, "hard-core" engineering topics are taught in lower division courses of undergraduate engineering programs. However, because precalculus mathematic is offered in most U.S. high schools, there is a reasonable possibility that some portions of traditional college-level engineering content knowledge could be downloaded to high school students, in order to streamline their pathway to engineering careers. Therefore, it is feasible to develop and implement a high school engineering curriculum that could be seamlessly connected to college engineering programs.

The Proposed Model for K-12 Engineering Curriculum is designed to solve the problem of the chronic shortage of engineering graduates in the United States, by offering K-12 students a better preparation for college-level engineering majors; it can selectively teach high school students appropriate

教师们将为学生提供咨询建议、指导、和评价的服务，并且教授同“顶石”项目相关的额外的课题。

核心的工程概念“超越使用工具的技能，…并且超越在过去的二十多年中已经引起了专业人士兴趣的数码技能。工具将发生变化但是甚至更加重要的是认知内容（cognitive content）和获取知识的过程（intellectual processes），它们对于有效地解决技术问题和读写能力（literacy）而言是不可或缺的”（桑德斯，Sanders，2008年，第6页）。关于一种以微积分之前的数学为基础的、但是属于“硬件核心”的（“hard-core”）高中工程课程的理念，作为本文所提议的模式的中心部件，是切实可行的。实用的工程师日常工作中经常使用的大多数同工程设计有关的基础的科学原理和分析技能，都是建立在微积分之前的数学（三角、代数、几何、和方程）的基础上的，某些时候需要初级的微积分（积分和微分）、以及对线性代数的相当大量的需要。传统上，“硬件核心”的（“hard-core”）工程课题是在大学本科低年级课程中教授的。尽管如此，因为微积分之前的数学是在美国大多数高中教授的，在合理的程度上有可能把传统的大学程度的工程知识内容的某些部分，下载给高中学生，以便使他们通向工程职业的路径更加通畅。因此，开发并推行一种可以同大学的工程教育无缝地连接起来的高中工程课程是切实可行的。

本文所建议的中小学工程教育课程模式（The Proposed Model for K-12 Engineering Curriculum）是为了解决美国长期短缺工程专业毕业生的问题而设计的，它将通过为中小学生提供一种更好的准备工作以便进入大学工程专业；它能够有选择地教授高中学生合适的、至今为止停留在大学本

engineering knowledge content (the "precalculus portions"), which up to this point, remain the domain of university undergraduate engineering programs. Adopting this model could allow high school graduates from engineering and technology curricula to have mastered a sufficient amount of engineering analytical skills that are transferable to undergraduate engineering courses, so they could spend a few weeks reviewing the "precalculus portions" of the course materials and then concentrate on the more difficult calculus-based portions. This would (a) give academically challenged high school students a better chance to pursue engineering studies as "early birds" and thus increase the enrollment of domestic students in undergraduate engineering majors; (b) give U.S. undergraduate engineering students the same "early bird" advantage over those in many other countries; and (c) give college engineering professors a better way to manage course schedules. The students would be more adequately prepared to handle the coursework, and this should improve the quality of undergraduate engineering education and reduce the dropout rate.

科工程教育课程的领域里的工程知识内容（"微积分之前的部分"，即"precalculus portions"）。采用这个模式可以让完成工程技术课程的高中毕业生掌握足够的、可以融入大学本科工程课程的工程分析技能，因此，他们可以花费数个星期的时间复习课程教学材料中的"微积分之前的部分"，然后集中精力学习难度更高的需要微积分的部分。这样做将（a）为学业上碰到困难的高中学生提供更好的机会、做为"早起的鸟儿"(early bird）捷足先登追求工程专业、因而增加国内学生在各种大学本科工程专业的入学率；（b）为美国大学本科工程专业的学生提供同样的"早起的鸟儿"捷足先登的利益、使他们相对于许多其它国家的学生具有优势地位；（c）为大学工程教授提供管理教学进度的更好的方式。学生们将会更加充分地准备好处理课业，这将改善大学本科工程教学质量并且降低退学率。

Second Component - Extracurricular Enrichment Program

第二个组成部分："课外加强学习项目"（Extracurricular Enrichment Program）

The Extracurricular Enrichment Program could be operated in two formats.

"课外加强学习项目"可以按照两种形式推行。

Infusing Engineering Topics into K-12 Mathematics and Science Courses.

把工程课题注入中小学数学和科学课程中

In addition to teaching engineering analysis and design through special Career Pathway courses, suitable engineering content could be incorporated into regular middle school and high school mathematics, chemistry, and physics courses, as extra teaching materials, word problems, and simple design projects. For example, in a geometry course, the engineering application of the triangular

除了通过特设的"职业路径"（Career Pathway）课程教授工程分析与设计之外，合适的工程内容可以纳入正常的初中和高中数学、化学、和物理课程中，作为补充的教学材料，应用题、和简单的设计作业。例如，在几何课中，可以向学生解释各种三角形在工程中的应用，比如说，三

shapes could be explained to students, such as a triangle is “indestructible,” unless the side lengths are changed, the shape would stay intact. In addition, triangular members are widely used in structural design; bridge design projects could be incorporated, with learning materials from the Internet, to study the subject of force equilibrium, to simulate bridge design with West Point Bridge Design software (http://bridgecontest.usma.edu/), and to build a scale model. Moreover, because triangles have one straight edge opposite a sharp corner, they can accommodate different shapes in threedimensional space and are used in the development of irregular or curved surfaces; thus, some topics of engineering sheet-metal design could be taught, giving the students an opportunity to design a transition piece, as shown in Figure 3. In a chemistry course, subjects of material selections could be incorporated. Other appropriate engineering topics could be identified by engineering and technology faculty and graduate students using well-established criteria, and gradually added to regular K-12 mathematics, physics, and chemistry courses as extra learning materials, through a process of pilot study or other mechanism of pedagogic experiment. This approach is simple, easy to implement, and virtually risk-free. It would not likely cause any disturbance to routine K-12 mathematics and science instruction.

角形是“坚不可摧”的（“indestructible”），除非边长被改变，形状将不会变化。除此之外，构成三角形的部件在结构设计中广泛使用；桥梁设计项目作业可以由网站中可以找到的学习材料配合、纳入学习“力平衡”（force equilibrium）的课题中，使用“西点桥梁设计” 软件（West Point Bridge Design，网址：http://bridgecontest.usma.edu/）模拟设计桥梁，并且建造缩尺模型。除此之外，因为各种三角形都有一个直边同一个锐角相对应，它们可以适应立体空间中的各种不同的形状并且用于不规则形状和弯曲面的构成中；因此，可以教授某些工程板金设计课题，给学生一个机会，设计一个过渡件（transition piece），如图 3 所示。在化学课中，可以纳入材料选择的课题。其它合适的工程课题可以由工程和技术教授以及研究生根据完善的标准加予选择，并且作为补充的学习材料，通过使用初步研究（pilot study）或其它教学试验机制的过程，逐步地加进中小学数学、物理、和化学课程。这个方式是简单易行的，并且没有风险。它将不太可能造成对于常规的中小学数学与科学课程教学程序的干扰。

Interdisciplinary Design Projects

Engineering design projects involving knowledge and skills from a variety of subjects could be implemented through after-school club activities or through training sessions during summer vacations. Such enrichment programs could provide students enrolled in STEM pathways an opportunity to (a) review previously learned scientific principles and skills while learning new ones that are relevant to the design projects;

跨科系的设计项目（Interdisciplinary Design Projects）

涉及取自各种不同的课题的知识与技能的工程设计项目可以通过课余俱乐部活动、或暑假训练班加予推行。这类“加强学习项目”（Enrichment Program）可以为在“科学、技术、工程、和数学路径”（STEM pathways）中注册的学生提供 机会，以便（a）复习以前学过的科学原理和技能，同时学习同设计项目有关的新的东

(b) integrate principles and skills from various STEM subjects and non-STEM subjects (e.g., social study, arts.), into practical design solutions; and (c) foster the ability to combine both “analytic reduction” and “system thinking” modes of the engineering design process, for solving real-world problems in a real-world manner. Mativo and Sirinterlikci (2005) developed an “animatronics” design project for student (Grades 7-12). It included an open-ended and creative project for the design of lifelike entertainment robots or dynamic and interactive animated toys with a mechatronic blob, penguin, robotic trash can, and a human-monster hybrid. These could cruise, wave swords, flip wings, and light eyes, in fun and creative team environments. They combined analytic and design skills from the following different but interconnected fields: (a) mechanical engineering (material and manufacturing process selection, including metals, ceramics, plastics and composites; mechanism design and assembly of levers and cranks, etc.); (b) electronics (actuators, sensors, controls); (c) microcontrollers’ structure and programming; (d) emerging technologies, such as muscle wires, air muscles, micro- and nanocontrollers; (e) two- and three-dimensional art (costuming from fabrics to rubber Latex, and modeling), and (f) industrial product design. The implementation of this project indicated that students’ academic performance improved through interdisciplinary engineering design activities. See figure 4. In summary, in addition to a Regular Curriculum, an Extracurricular Enrichment Program would be an effective supplement to help consolidate students’ mastery of fundamental knowledge and creative design ability.

西；（b）综合运用取自各种不同的科学、技术、工程、和数学课题的原理和技能、以及非科学、技术、工程、和数学课题的知识（如社会研究和艺术等等），找到实用的设计解决方案；（c）培养把工程设计过程中的“解析约简”（analytic reduction）和“系统思维”（system thinking）这两种模式综合运用的能力，以现实世界的方式解决现实世界的各种问题。马提伏和西林特里克奇（Mativo and Sirinterlikci，2005年）为第7年级至第12年级（Grades 7-12）的学生制定了一个“动物电子”（Animatronics）设计项目。它包括一个开放型的、创新性的项目，设计一个仿生的、娱乐性的机器人，或动态的、互动的玩具，包括一个机械电子团块、企鹅、机器人垃圾桶、以及一个人类和怪物混血的杂种动物。这些构件可以在一种有趣的、创意的团队环境中，巡航、挥舞宝剑、拍动翅膀、闪亮眼睛。它们综合了来自如下的各自不同但是又互相关联的学科中的分析和设计技能：（a）机械工程（材料和制造程序的选择、包括金属、陶瓷、塑料和复合材料、机械设计、杠杆和曲柄的组装，等等）；（b）电子（执行器、传感器、和控制器）；（c）微型控制器结构与编程；（d）新型技术如肌丝（muscle wires）、空气肌肉（air muscles）、微型和纳米控制器（micro- and nanocontrollers）；（e）平面和立体美术（利用布料和橡胶胶乳制作服装、造型建模）；以及（f）工业产品设计。如图4所示，这个项目的推行表明学生的学业表现在跨科系的工程设计项目中得到改善了。综上所述，在“正规课程”（Regular Curriculum）之外，“课外加强学习项目”（Extracurricular Enrichment Program）将是一种行之有效的增补构件，可以帮助巩固学生对于基础知识和创意设计能力的掌握。

Table 1. Regular K-12 Engineering Curriculum Flow Chart

Grades K-5 (Kindergarten & Elementary School) →For all students	**Grades 6-8 (Middle School)** →For all students, especially the STEM-oriented ones	**Grades 9-11 (High School)** →For all Engineering Pathway students	**Grade 12 (High School Graduation Year)** →For all Engineering Pathway students
Knowledge Content (Course Works)			
STEM Courses (2 courses; throughout Grades K-5): 1st Course (Grades K-5) - Mathematics. 2nd Course (Grades K-5) - Integrated Science, Engineering and Technology: • General Principles of Science, Engineering and Technology; • Diverse Topics in Science, Engineering and Technology; • Ecologically Sustainable Application of Science, Engineering and Technology. • Careers & Ethics in Science, Engineering and Technology. →	Mathematics & Science (2 courses; throughout Grades 6-8). Technology (8 Subjects organized into 4 Full Year Courses; 1 Course per Grade/Year): 1st Course (Grade 6) - Product Design & Manufacturing: • Engineering Drafting, Solid Modeling & Product Design; • Manufacturing Systems. 2nd Course (Grade 7, an extension to Grade 6 Science Course) - Humans & Environment: • Power & Energy; • Construction Systems. 3rd Course (Grade 8) - Technology Aesthetics & Ergonomics: • Digital Graphics Design & Product Aesthetics; • Ergonomics, Safety & Appropriate Technology Development. 4th Course (Grade 8, to be taught as a part of Science Course) - Electronics & Control Technology: • Electrical Circuitry Design, Component Selection & Digital Simulation; • • Robotics Assembly & Programming. →	Mathematics & Sciences (2 courses; throughout Grades 9-11. For Sciences, Physics and Chemistry are mandatory). Engineering Foundation (Several Subjects organized into 3 Courses; 1 Course per Semester): 1st Course (Grade 9, 1st Semester) - Engineering Mechanics I: • Statics & Dynamics; 2nd Course (Grade 9, 2nd Semester) - Engineering Mechanics II: • Fluid Mechanics & Aerodynamics; • Heat Transfer & Thermodynamics. 3rd Course (Grade 10, 1st Semester) - Engineering Materials: • Strength of Materials; • Materials Properties, Treatment & Selection. Engineering Pathway (3 courses; 1/semester; 2nd Semester of Grade 10, 1st and 2nd Semester of Grade 11). → Note: For non-Engineering Pathways (Science, Technology and mathematics), the Foundation and Pathway courses would be different.	Design "Capstone" (2 Courses at Grades 12). 1st Course (Grade 12, 1st Semester) – Engineering Design Capstone I: • Mini Lesson: Engineering Economics, and other topics relevant to the design project; • Design activities (teamwork). 2nd Course (Grade 12, 2nd Semester) - Engineering Design Capstone II: • Design activities (teamwork). • Prototyping activities (teamwork). Note: For non-Engineering Pathways (Science, Technology and mathematics), the Design "Capstone" courses would be changed to Research or Manufacturing "Capstone."
Mode of Design Process			
Creative, Conceptual and light analytic (assignments). →	Engineering & Technology Experiment (assignments). →	Analytic Reduction" for "Well-structured problems ("Mini Capstone" or final design or research project for each course) →	Ill-structured and Systems Thinking" ("Capstone" graduation project)

表1.中小学正规工程课程（Regular K-12 Engineering Curriculum）流程图

第K年级至第5年级（Grades K-5，幼儿园到小学） →适用所有学生	**第6年级至第8年级（Grades 6-8，初中）** →适用所有学生，尤其是学业方向为科学、技术、工程和数学（STEM）者	**第9年级至第11年级（Grades 9-11，高中）** →适用所有选择“工程路径”（Engineering Pathway）的学生	**第12年级（Grade 12，高中毕业年级）** →适用所有选择“工程路径”（Engineering Pathway）的学生
知识内容（课业）			
<u>科学、技术、工程和数学（STEM）课程</u> （2门课；贯穿第K年级至第5年级的所有年级） 第1课（第K年级至第5年级的所有年级）- 数学课 第2课（第K年级至第5年级的所有年级）- 科学、技术、和工程综合课： • 科学、工程、和技术的一般原理； • 科学、工程、和技术的多种课题； • 生态可持续的科学、工程、和技术的应用； • 科学、工程、和技术的职业和伦理。 →	<u>数学和科学课程</u> （2门课；贯穿第6年级至第8年级的所有年级） <u>技术</u> （8门科目，组成4门一整年的课程；每年/每年级1课） 第1课（第6年级）- 产品设计和制作： • 工程绘图、实体造型和产品设计； • 制造系统。 第2课（第7年级，是对第6年级科学课程的延续）- 人类和环境： • 电力和能源； • 建筑系统。 第3课（第8年级）- 技术美学和人机工程学： • 电脑图案设计和产品美学； • 人机工程学、性能安全、和合适的技术开发。 第4课（第8年级，作为科学课程的一部分教授）- 电子学和控制技术： • 电路设计、零部件选择、和设计模拟； • 机器人组装和编程。 →	<u>数学和科学</u> （2门课；贯穿第9年级至第11年级的所有年级），在科学科目中，物理和化学是必修课。 <u>工程基础</u> （多种科目组成3门课；每学期1课）： 第1课（第9年级，第1学期）- 工程力学（上）： • 静力学和动力学。 第2课（第9年级，第2学期）- 工程力学（下）： • 流体力学和空气动力学； • 传热学和热力学。 第3课（第10年级，第1学期）- 工程材料： • 材料强度； • 材料性质、处理和选择。 <u>工程路径</u>（Engineering Pathway，3门课；每学期1课；第10年级第2学期，第11年级第1和第2学期） → 备注：对于非工程的路径（科学、技术和数学）而言，基础课程（Foundation courses）和路径课程（Pathway courses）将是不同的。	<u>设计“顶石” 课程</u> （Design “Capstone”，2门课，第12年级） 第1课（第12年级，第1学期）- 工程设计“顶石”课（上）（Engineering Design Capstone I）： • 袖珍课（Mini Lesson）：工程经济学、和同设计项目有关的其它课题； • 设计活动（团队作业）。 第2课（第12年级，第2学期）- 工程设计“顶石”课（下）（Engineering Design Capstone II）： • 设计活动（团队作业）。 • 模型制作活动（团队作业）。 备注：对于非工程的路径（科学、技术和数学）而言，设计“顶石” 课程（Design “Capstone” courses）将被改为研究或制作“顶石” 课程（Research or Manufacturing “Capstone”）。
设计过程的模式			
创意性的、概念性的、和轻度的分析（作业）。 →	工程和技术实验（作业） →	解析约简（Analytic Reduction），解决结构良好的问题，如“袖珍顶石”（“Mini Capstone”）或每一课的期末设计或研究作业。 →	系统思维（Systems Thinking），解决结构不良的问题，如“顶石”毕业项目作业（“Capstone” graduation project）。

Table 2. Commonly Shared Undergraduate Lower-Division Engineering Foundation Courses Among Various Engineering Programs at the University of Georgia, Based on Data from Undergraduate Engineering Program Hadouts (Available from Room 120, Driftmier Engineering Center, Athens, Georgia 30602)

University of Georgia Engineering Program	University of Georgia Engineering Foundation Courses								
	ENGR 1120 Graphics & Design	ENGR 2120 Statics	ENGR 2130 Dynamics	ENGR 2140 Strength of Materials	ENGR Fluid Mechanics	ENGR 3140 Thermo-dynamics	ENGR 3150 Heat Transfer	ENGR 2920 Electrical Circuits	ENGR 2110 Engineering Decision Making
B.S. in Agricultural Engineering									
Electrical & Electronic Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mechanical Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Natural Resource Management	✓	✓	✓	✓	✓	✓	✓	✓	✓
Structural Systems	✓	✓	✓	✓	✓	✓	✓	✓	✓
Process Operations	✓	✓	✓	✓	✓	✓	✓	✓	✓
B. S. in Biological Engineering									
Environmental Area of Emphasis	✓	✓		✓	✓	✓	✓	✓	✓
Biochemical Area of Emphasis	✓	✓		✓	✓	✓	✓	✓	✓
Biomedical Area of Emphasis • Biomechanics Track • Instrmentation Track	✓	✓		✓	✓	✓	✓	✓	✓

表 2. 佐治亚大学（the University of Georgia）各种工程专业的本科低年级通常共有的基础课程，根据在德里弗特米尔工程中心（Driftmier Engineering Center，地址：Athens, Georgia 30602）得到的《本科工程教育课程表》（Undergraduate Engineering Program Handouts）所提供的资讯整理

佐治亚大学（The University of Georgia）工程教育	佐治亚大学工程基础课程								
	ENGR1120 绘图与设计（Graphics & Design）	ENGR 2120 静力学（Statics）	ENGR 2130 动力学（Dynamics）	ENGR 2140 材料强度（Strength of Materials）	ENGR X 流体力学（Fluid Mechanics）	ENGR 3140 热力学（Thermo-dynamics）	ENGR 3150 传热学（Heat Transfer）	ENGR 2920 电路（Electrical Circuits）	ENGR 2110 工程决策（Enginerering Decision-Making）
农业工程科学学士学位（B. S. in Agricultural Engineering）									
电机与电子系统（Electrical & Electronic Systems）	✓	✓	✓	✓	✓	✓	✓	✓	✓
机械系统（Mechanical Systems）	✓	✓	✓	✓	✓	✓	✓	✓	✓
自然资源管理（Natural Resource Management）	✓	✓	✓	✓	✓	✓	✓	✓	✓
结构系统（Structural Systems）	✓	✓	✓	✓	✓	✓	✓	✓	✓

过程操作（Process Operations）	✓	✓	✓	✓	✓	✓	✓	✓	✓
生物工程科学学士学位（B. S. in Biological Engineering）									
环境专业（Environmental Area of Emphasis）	✓	✓		✓	✓	✓	✓	✓	✓
生物化学专业（Biochemical Area of Emphasis）	✓	✓		✓	✓	✓	✓	✓	✓
生物医学专业（Biomedical Area of Emphasis: • Biomechanics Track • Instrumentation Track）	✓	✓		✓	✓	✓	✓	✓	✓

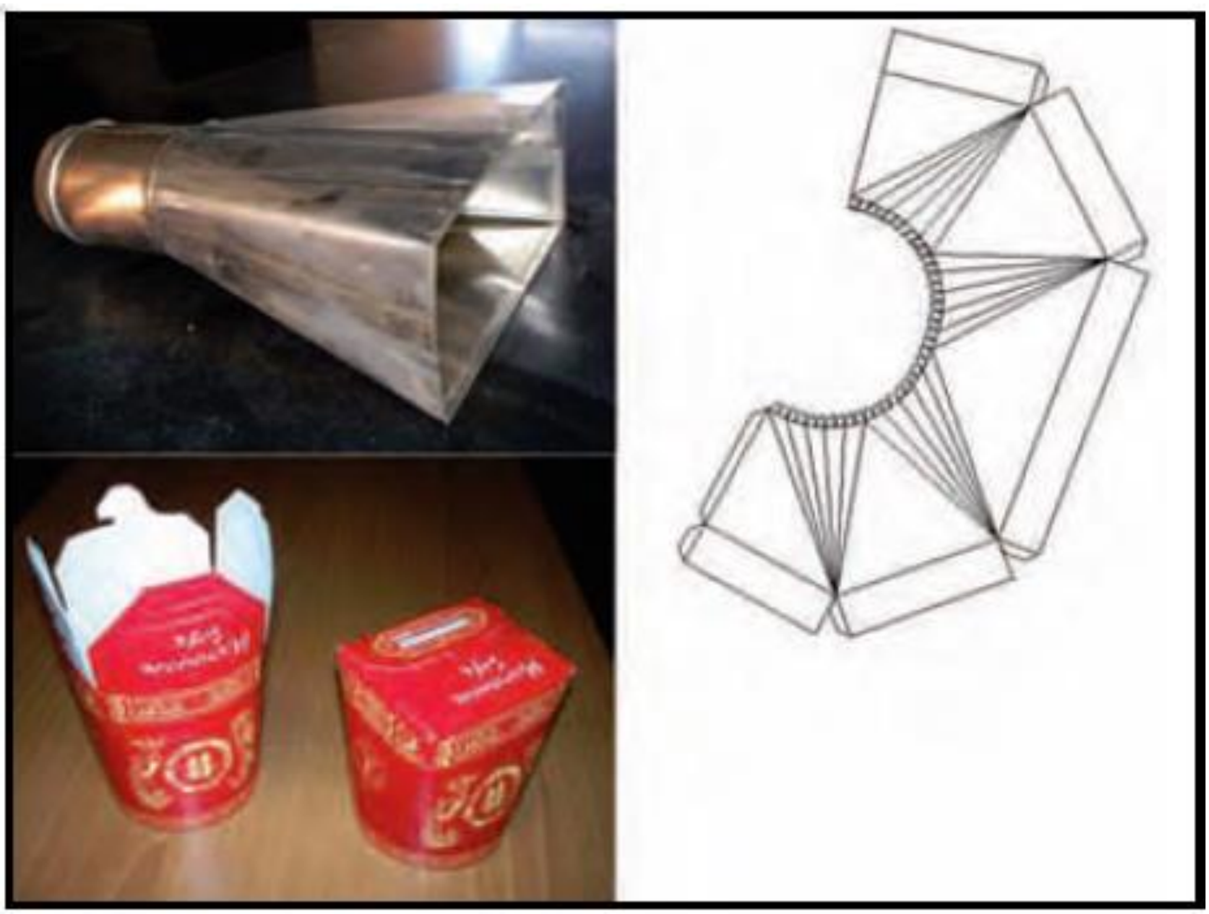

Figure 3. Examples of circle-to-square transition pieces (sheet-metal connector and restaurant take-home food container).

图 3. 从圆形到方形的过渡件的实例（板金连接件和餐馆外卖食物容器）。

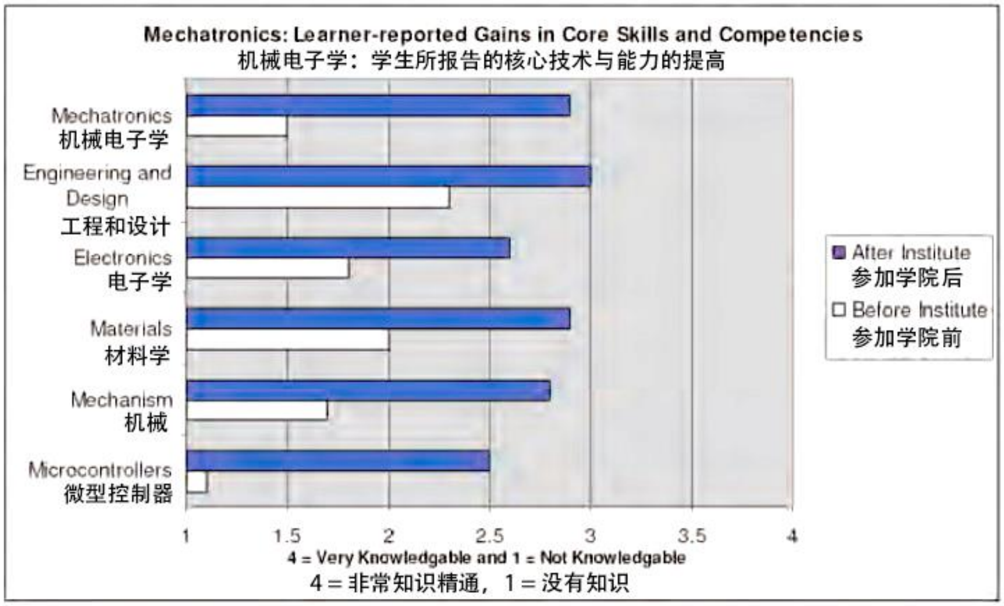

Figure 4. Sirinterlikci and Mativo's Animatronics project helped students improve STEM learning through inclusion of engineering design (Mativo & Sirinterlikci, 2005a).

图 4. 西林特里克奇（Sirinterlikci）和马提伏（Mativo）的动物电子（Animatronics）设计项目，通过注入工程设计，帮助学生改善科学、技术、工程和数学学业表现（Mativo & Sirinterlikci, 2005a）。

Potentially Realistic Students' Learning Outcomes

For students enrolled in K-12 Engineering Curriculum, when they graduate from high schools, they could realistically be expected to have (a) built a solid foundation in precalculus mathematics and sciences; (b) learned the basics of engineering-related industrial arts and digital modeling and simulation technology; (c) mastered a sufficiently large portion of precalculus based engineering analytic principles and predictive computational skills; and (d) become familiar with various modes of the engineering design process. These potentially realistic learning outcomes could give these students the freedom to choose any of the following:

潜在地能够实现的学生学习成果

（Potentially Realistic Students' Learning Outcomes）

对于在中小学工程课程里注册的学生来说，当他们从高中毕业的时候，他们有可能实现的预期的目标将包括（a）为微积分之前的数学和科学打下牢固的基础；学到同工程有关的工艺技术和电脑立体模型制作以及模拟技术有关的基础知识；（c）掌握足够的、大量的、以微积分之前的数学为基础的工程分析原理和预测性的计算技能；而且（d）熟悉各种模式的工程设计程序。这些潜在地能够实现的学生学习成果，将给这些学生从如下各项中选择的自由：

(1) Enrollment in college engineering programs as full-time students with a solid mastery of the precalculus-based portions of foundation courses as well as practical engineering design and research skills; or

(2) Entry into job market as technical employees, such as CAD drafters with some entry-level ability to design simple products (e.g., furniture, tools, toys with electronic devices and kitchen appliances with simple circuitry and mechanical components), while enrolling as part-time students in engineering and technology programs, including two-year technical certificate or four-year bachelor of science degrees; or

(3) Enrollment in non-engineering university undergraduate majors (e.g., science and mathematics) with useful abilities and skills for lifelong career enhancement; for example, a future scientist or mathematicians would be able to design and prototype devices to facilitate experiments or teaching.

Notice that the aforementioned choices are simply convenient suggestions, and by no means do they constitute any intended idea about "academic tracking." If the Proposed Model were adequately implemented, then all students enrolled in K-12 STEM Career Pathways (all types of achievers), could be better prepared for a science or engineering major at the college level. Therefore, the Proposed Model should be considered as an egalitarian (although upward mobile and flexible) model that promotes equal preparation for college engineering majors from an academic perspective; it would be up to the students to choose their Career Pathways. The ultimate purpose of the Proposed Model is to educate new generations of innovative engineers or professionals in other fields. This could be accomplished by launching K-12 students early into engineering studies, so that they

（1）在大学工程专业中注册做全时间（full-time）学生，具备对于基础课程中微积分之前的部分的牢固的掌握、以及实用的工程设计和研究技能，或

（2）进入就业市场做技术雇员，如使用电脑辅助设计软件的、具备设计简单的产品（如家具、工具、含有电子部件的玩具、和含有某些简单的电路和机械部件的厨房用具）的能力的、入门级的绘图员（CAD drafters），同时做半时间（part-time）的学生，攻读工程和技术专业，包括两年制技术证书或四年制科学学士学位；或者

（3）进入非工程的大学本科专业（例如科学和数学），具备对终生的职业发展有用的能力和技术；例如，一个未来的科学家或数学家将有能力设计并制作器具方便实验或教学。

请注意上述的各种选项仅仅是方便的建议而已，并且绝对不是构成"学业分等级"（academic tracking）的意念。如果本文所建议的模式能够适当地推广，那么，在"中小学科学、技术、工程、和数学职业路径"（K-12 STEM Career Pathways）中学习的所有的学生（不管他们的学业成绩如何），都将能够为了攻读大学科学或工程专业做出更好的准备。因此，本文所建议的模式将被视为一种追求平等的（但是是向上流动的和灵活的）模式，它将从学术的角度上促进学生们平等地准备进入大学工程专业；它将让学生们自愿地选择自己的职业生涯。本文所建议的模式的最终目的，是教育培养新的几代的富有创新精神的工程师或其它领域的专业人才。这个目标可以通过尽早地把中小学生送上工程专业的轨道、以便使他们能够在生活中尽

could foster analytic and innovative capacities early in life. Modern engineering education is more complicated than ever before, due to the explosion of new knowledge and technologies, especially those related to digital modeling and simulation. In addition, traditional engineering education has been somehow challenging to students due to heavy requirements on calculus-based mathematics, physics, and engineering course work. Therefore, engaging students early in the Engineering Career Pathways would make sense. It is not this author's expectation for K-12 students to become instantaneous robotic designers or spacecraft engineers (although the highest academic achievers among them should be given adequate preparation for careers of vital national interests). This is generally beyond their cognitive maturity (except in some high-achieving communities where economic and educational conditions might magically allow this to happen); instead, we should aim at matching K-12 engineering and technology education with the cognitive maturity level of average K-12 students. Taking the Mechanical Engineering Career Pathway as an example, they could be expected to graduate from the program with some creative abilities and analytic skills to design and prototype everyday products or systems, with simple mechanical and electronic components (either of their own design or from out-of-shelf selection), which are professionally ready for production or installation; and these could include toys, utensils, furniture, clothing, and fastening devices. This might be doable for average high school graduates. But they should not be expected to design robots except the very simple ones using out-of-shelf components. Expecting too much from K-12 students without a reasonable chance to succeed would not be the best way to prepare them for a brilliant engineering career. This line of

早地培养分析和创新能力来实现。由于新知识和新技术、尤其是同数码建模和模拟（digital modeling and simulation）有关者的爆炸性发展，现代工程教育比从前更加复杂。除此之外，传统的工程教育因为对于微积分为基础的数学、物理、和工程课程的繁重的要求，在某种程度上已经对学生们构成挑战。因此，让学生尽早地走进“工程职业路径”（Engineering Career Pathways）将是明智的。本文作者的指望并不是所有的中小学学生都在一瞬间成为 机器人设计家或飞行器工程师（虽然，必须为他们当中的学业成绩最优秀者提供充足的准备，以便从事这类攸关国家重大利益的职业）。这种指望是远远超过他们的智力成熟程度的（唯一的例外是，在某些高成就的社区，经济的和学习的条件将有可能神奇般地允许这样的奇迹发生）；相反地，我们的目标应当是把中小学工程和技术教育同一般的中小学生的智力发育程度相匹配。以机械工程职业路径（Mechanical Engineering Career Pathway）为例，应当指望从这一项目毕业的学生具备某些创新能力和分析技能，以便设计并制作包含简单的机械和电子部件（或者是自己设计的、或者是从货架上买来）的、符合专业水平的、做好投产或安装准备的日用产品或系统的模型；这些可以包括玩具、器皿、家具、衣服、和固定装置。这样做，对于典型的高中毕业生来说可能是切实可行的。但是他们不应当被指望设计机器人，除了非常简单的、利用从货架上买来的零部件组装的以外。对中小学生指望得太多而又没有合理的获得成功的希望，将不会是帮助他们做好准备从事辉煌的工程职业的最佳方式。这一条思路，是

thinking is compatible with the "everyday technology" idea of broadly defining "the term technology to include the artifacts of everyday life as well as environments and systems," of "focusing on the technologies of everyday life," and of allowing children to "solve problems of real significance in their lives," which have been explained by Benenson (2001, pp. 730-732), in presenting his 10-year long City Technology project.

同波能森（Benenson，2001 年，第 730 至 732 页）在介绍他的长达 10 年的"城市技术项目"（City Technology Project）时所解释的、在广义上界定"技术这个术语包括日常生活的器物以及环境和系统"、"把重点放在日常生活的技术"、以及允许学生们"解决在他们的生活中有着实际意义的问题"的"日常的技术"的想法相吻合的。

Potential Benefits of the Proposed Model

The Proposed Model's most important potential benefit is the symbiotic integration of specific engineering analytic knowledge content with various modes of generic engineering design process, for it is self-evident that without teaching K-12 students particular age-appropriate engineering analytic and predictive knowledge content, they could not build a solid foundation of knowledge and skills for further study of engineering at college level. Also, without giving such students opportunities to practice age-appropriate engineering design, they would not be able to synthesize various sets of knowledge and skills into practical solutions of realworld problems and to form appropriate engineering thinking habits. The aim of infusing engineering analytic and predictive principles and computational skills into a potentially viable K-12 engineering curriculum is NOT to make students instruments of computations, or to encourage rote memorization of engineering analytic principles and computational formulas, or their applications in solving a few simple homework problems in the purely "Analytic Reduction" model (although all of the above are necessary tasks); however the aim is to foster the real ability of solving real-world problems, which involve integration of engineering analytic principles. It also involves, of course, computational formulas, from various subjects, as well as knowledge

所建议的模式的潜在的各种益处

本文所建议的模式的最重要的益处，是把特定的工程分析知识内容、同各种各样的通用的工程设计程序互惠互利地、共生地结合起来，因为不言而喻地，没有教授中小学学生特定的、适合年龄的工程分析和预测方面的知识内容，他们将无法建立牢固的知识与技能的基础，去进一步学习大学工程专业。同样地，没有给这些学生实践适合年龄的工程设计的机会，他们将无法把各种门类的知识和技能综合运用到解决真实世界中的问题的切实可行的方案中、并且培养适当的工程思维习惯。把工程分析和预测原理、以及计算技能注入一个切实可行的、有活力的中小学工程课程的目的，绝不是为了把学生改造成为计算的工具、或者鼓励死记硬背工程分析原理和计算公式、或者以纯粹的"解析约简"（Analytic Reduction）的模式应用它们解决很少的几个家庭作业中的问题（虽然以上所有的这些都是必须完成的任务）；尽管如此，本文所建议的模式的目标是培养解决真实世界中的问题的实际技能，这涉及到对工程分析原理的综合运用。它当然同样地涉及到把来自各种课题的计算公

from art, social and ecological studies, and others, into a “system thinking” model of holistic problem solving. This focus on solving problems could foster students’ real ability in innovative engineering design that is based on solid mastery of necessary analytic tools. This would allow them to use the generic engineering design approach to create real-world quality products and systems, which are appropriate to their age, technically feasible, and socially and ecologically appropriate.

式、以及来自美术、社会和环境科学、和其它领域的知识，综合运用到一种“系统思维”（“system thinking”）的、全面而整体地解决问题的模式中。这样以解决问题为重点将能够培养学生们在对必要的分析工具的牢固掌握的基础上，进行创新性工程设计的真正的技能。这样做将允许他们运用通用的工程设计方法，创造真实世界中的高质量的、适合他们的年龄的、技术上可行的、对社会负责任的、有利于环境保护的产品和系统。

Conclusions

This article has provided a workable framework for defining K-12 age-appropriate engineering knowledge content and an outline for a new paradigm for a streamlined, cohesive, and optimized lifelong STEM education in the United States, with a focus in engineering. For additional details of the Proposed Model, please contact the author at edwardnlocke@yahoo.com. In order to improve K-12 engineering education, the following recommendations and plans are hereby presented for consideration, support, and implementation:

1. Organization: Establish a network of stakeholders, to include, (a) government officers in charge of K-12 STEM education at Federal and state levels, (b) leaders of National Centers for Engineering and Technology Education and other institutions of authority in K-12 engineering education, (c) scholars in the fields of engineering and technology education from universities and research institutions, (d) school district administrators and engineering and technology teachers, (e) representatives from the business community and nonprofit organizations, and (f) university engineering students. This network could offer

结论

本文已经提供了用来界定适合中小学生年龄的工程知识内容的一个框架，以及一个流线型的、紧密结合的、最有效率的、终生的美国中小学科学、技术、工程、数学课程的范例的大纲，这个范例以工程作为着重点。想要得到有关本文所建议的模式的更多的详情，请同作者联系（电子邮箱：edwardnlocke@yahoo.com）。为了改善中小学工程教育，谨在此提出如下的建议和计划，供考虑、支持和实施：

（1）组织：建立一个利益攸关者的网络，包括（a）联邦和州一级的负责中小学科学、技术、工程、数学教育的政府官员；（b）全国科学和技术教育中心（National Centers for Engineering and Technology Education）、和其它负责中小学工程教育的权力机构的领导者；（c）大学和研究机构中工程和技术教育领域的学者；（d）学区行政主管官员和工程与技术教师；（e）企业界和非盈利机构代表；以及（f）大学工程系学生。这个网络将能够为利益攸关

stakeholders an opportunity to discuss specific policies, measures, actions to be taken for the solution of problems listed in the report by the Committee on K-12 Engineering Education (2009). It could also offer them criticism and advice regarding the improvement of the model of the K-12 Engineering Curriculum proposed in this article, so that it could eventually become a collective proposal accepted by all or most of the stakeholders.

2. Research: Continue research on defining K-12 age-appropriate engineering knowledge content from the following subjects: dynamics, strength of materials, material science, heat transfer, thermodynamics, engineering economics, aerodynamics, and mechanism design; this will lead to the eventual publication of *The Handbook of Proposed Engineering Topics with Analytic Principles, Computational Formulas and Units for K-12 Schools (with Reviews for Mathematics and Sciences).* This research constitutes the most important prerequisite for the implementation of the K-12 Engineering Curriculum proposed in this article. It would be an important reference for the development of K-12 engineering teaching materials and the improvement of K-12 engineering and technology teacher training programs.

3. Pilot study: K-12 schools (especially high schools, including charter schools) could be found to conduct pilot pedagogic experiments to determine the ageappropriateness of all K-12 feasible engineering analytic knowledge content to be identified in the above-mentioned *Handbook* to be published in the near future.

者提供一个机会，探讨为了解决中小学工程教育委员会（The Committee on K-12 Engineering Education，2009年）报告所开列的问题所应当采取的特定的政策、措施、和行动。它同样地可以提供关于改善本文中所建议的模式的批评和建议，以便使它最终能够成为一个集体的建议，为各方面的或大多数的利益攸关者所接受。

（2）研究：继续进行界定适合中小学年龄的工程知识内容，包括如下学科：动力学、材料力学、材料科学、传热学、热力学、工程经济学、空气动力学、和机械设计；这将最终导致*《适合中小学校的工程课题及其分析原理、计算公式和单位（包括数学与科学课题的复习）建议手册》*（*The Handbook of Proposed Engineering Topics with Analytic Principles, Computational Formulas and Units for K-12 Schools (with Reviews for Mathematics and Sciences*)的发表。这项研究将构成实施本文中所建议的中小学工程课程的最重要的先决条件。它将成为开发中小学工程教学材料和改善中小学工程和技术教师训练项目的一本重要的参考书。

（3）初步研究（Pilot study）：可以找到一些中小学校（尤其是高中，包括特许学校）进行初步的教学实验，以便确定在不久的将来将要发表的上述《手册》中所选定的所有的中小学可能适合的工程分析知识内容的实际上的合适性。

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