Printable 3D Models for Customized Hands-on Education

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Abstract

Physical models are an important form of hands-on active learning that is increasingly being replaced by virtual simulations. In this paper I propose that rapid prototyping technology has the potential to reverse this trend, and reap the educational benefits while eliminating many of the logistic difficulties that have lead to it. Moreover, the use of rapid prototyping can offer new opportunities to enhance accessibility to physical teaching models and customize them for specific personal learning needs, thereby opening new educational possibilities. To accelerate this opportunity, we have established a repository of 3D-Printables models for education at www.3dprintables.org.

Introduction

Many educators recognize the importance of hands-on models and have designed and constructed physical demonstration models for teaching: Walking around the halls of many universities one can often see many teaching models, such as mechanical models for teaching kinematics and dynamics, and ball-and-stick models of complex molecules for teaching chemistry. But these models are often old and underused, and are being slowly replaced with cheaper and more flexible virtual simulations; Physical models are rarely made or shared outside of an educational institute because of the costs involved in making, maintaining, and shipping models, model fragility, and other logistical constraints.

Rapid prototyping technology has the potential to reverse this trend, and reap the educational benefits of physical models for hands-on education while eliminating many of the logistical difficulties that are hampering this form of education. Freeform fabrication processes allow direct 3D fabrication of complex 3D shapes without the need for special manufacturing skills, tooling and resources, thereby allowing educators to easily design and realize many models. Moreover, the ability to electronically share model files promotes the exchange and sustained improvement of teaching models by the educational community, thereby motivating their development. The dropping prices of rapid prototyping equipment and services, as well the availability of cheap do-it-yourself fabricator kits [38] promises to increase the accessibility of this technology.

But rapid prototyping can go beyond just reviving traditional model making – it can provide new opportunities through mass customization. While traditionally the lengthy design and fabrication process of a teaching model required that educators choose among a fixed repertoire of models, on-demand printing allows for these models to be adjusted to fit a personally-customized curriculum.

Teaching model customization can occur at several levels. Students can select a specific model for a topic of their interest, without requiring stocking complete series: For example, a library of thousands of protein models can allow downloading and printing any single molecule model on demand. Models can be fabricated at various scales to suit their target use (e.g. personal use or large-class demonstrations), and to meet allocated budget. With more adjustment, models can be fabricated with different densities, materials, colors, surface properties and internal structure to demonstrate various properties such as friction and inertia. Ultimately, models can be modified in more intricate ways to demonstrate more subtle issues, and models can be modified by students themselves to answer questions and to explore new directions – that may have been unforeseen by the original model designer.

Motivation for physical models in education

Physical models are important for active learning

There is ample evidence that learning is enhanced through active experiences [1,17]. This is especially true when spatial and physical concepts are involved that are difficult to visualize and understand abstractly [3], even with the help of simulations and virtual models. A study of knowledge retention showed that only about 20% of knowledge is retained when only abstract conceptualization is involved, but as much as 90% of is retained when the concrete experience is involved [30]. Learning theories and practical studies also suggest that a significant portion of undergraduate engineering students are sensory types that require hands-on experience to be engaged. Stone ad McAdams [31] report overwhelming success in teaching using concrete physical manipulation, and describe it as a 'counter culture' to the trend of increasingly virtual-analysis based education.

Physical models may alleviate some learning disabilities

Students with some types of disabilities would benefit from physical teaching models even more directly. Approximately 24,000 children and students in the U.S. suffer from severe visual impairment [33], allowing them to acquire spatial concepts only through verbal description or direct hands-on manipulation. Less severe but more pervasive and more difficult to diagnose are students with visual spatial perception learning disabilities [32]; these students have difficulty perceiving spatial concepts from 2D pictures or descriptions, and benefit directly from hands-on manipulation.

Physical models may help alleviate gender disadvantages due to differences in spatial reasoning and cognition

The importance of hands-on manipulatives for teaching engineering may also help in alleviating gender-based disadvantages in spatial perception. Men often outperform women in tasks that require spatial ability [1,22,27,18,35,24,6,14,10], the use of which is paramount to success in engineering and the sciences. For example, mental rotation is the ability to imagine the transformation of a 3D object, and this ability has shown a consistent pattern of gender differences [11,34]. Men rotate objects faster [9,21] and more accurately [13,16,18,24,35] than women. Several factors may contribute to these gender differences, including gender-based socialization, practice, experience, and beliefs about their own capabilities.

The factors that that govern spatial perception abilities are subjects of numerous studies [6] but individual's prior *experience* with spatial tasks is key [4], and the experiences that provide such practice are more common for boys [29]. Male children are encouraged to play with construction toys that require spatial manipulation more than female children [2,5,6,14,18]. In a vicious circle, lack of practice tends to reduce motivation and increase the likelihood of failure and discouragement, thereby further lessening the chances of engaging in spatially oriented tasks [29]. If gender differences in spatial abilities are connected to parental encouragement in gender-stereotyped activities, then practice or training in spatial activities might eliminate, or at least alleviate, these differences. Indeed, with some types of training women may increase their performance to the level of men [10].

Spatial perception is important in all engineering and science fields, but is particularly critical in fields like mechanical engineering, civil engineering, and architecture, which involve extensive use of 3D geometry. Other fields, like biology, chemistry, material science and nanotechnology also increasingly require understanding of spatial concepts at the nano and micro scale.

Creating an online library of printable teaching models

Our goal is to provide renewed opportunities for educators to use and share physical teaching models across all disciplines. The website www.3dprintables.org. is a wiki-style public library of printable educational models that will allow educational institutes equipped with rapid prototyping equipment to share and fabricate accurate, full-size, functional models for education. Some example functional models [12] are shown in Figure 1.

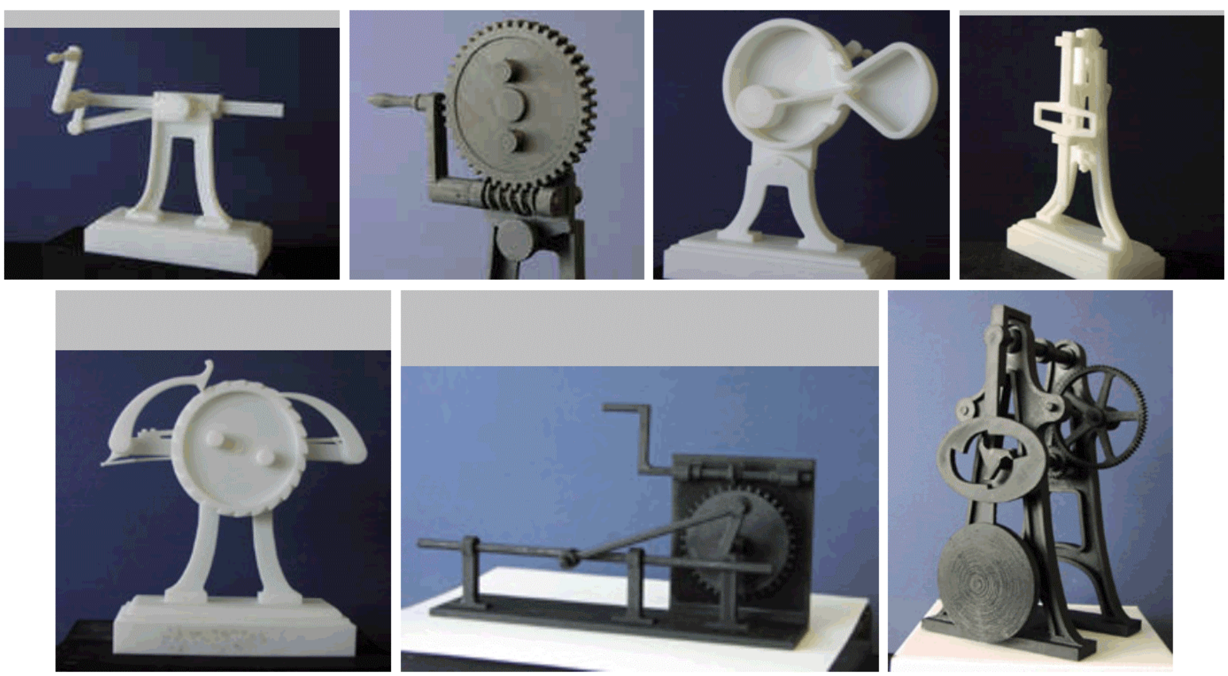

Figure 1. Printable models for teaching kinematics [26], STL files available for download

Models in the library can span across many disciplines, with a wide range of physical scales and mathematical abstraction:

- Models for Biomechanics: e.g. Finger and knee joints, tendon extensor mechanisms
- Models for Biology: e.g. folded proteins, demonstrating docking geometries
- Models for Aeronautics: e.g. wing shapes, wind-tunnel models

▪ Models for Math: e.g. 3D fractals, knots, polytopes, manifolds, regular polygons

Besides printable models, the library contains the source CAD models that generated the printable files, in order to facilitate their modification and extension. Additional software allows generation of models directly from data, such as molecule models from PDB files.

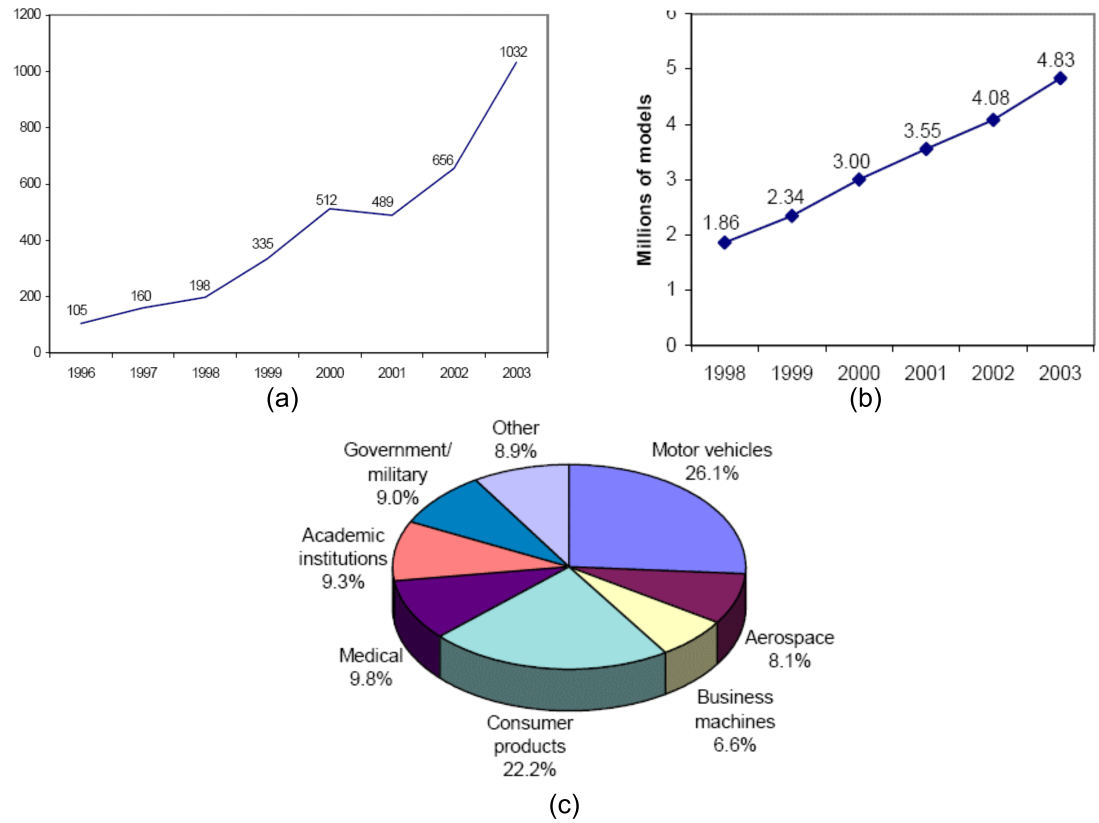

Figure 2. **Trends in rapid prototyping market in 2003** (a) 3D Printer sales from 1996 to 2003 (b) Estimated RP Model production (c) Major industrial sectors using RP technology. Academic sector grew 4.1%. Source: Wohlers Associates, Inc. [37]

Conclusions

Commercial SFF technology and hobby platforms [38] combined with a rich library of printable educational models could greatly expand availability and sharing of hands-on teaching instrumentation, and, more importantly provide the *incentive* for designing more models in the future. Though rapid prototyping machines are still expensive and not available in at all undergraduate universities, their prices are dropping rapidly and it is likely that within a decade they will be commonplace. Machine sales are increasing exponentially, 3D printing activity is at a steady rise, and the market share of academia is increasing too (Figure 2). This trend can be exploited to revive one of the important forms of hands-on active learning, as well as to address one of the challenges of mass-customized education.

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