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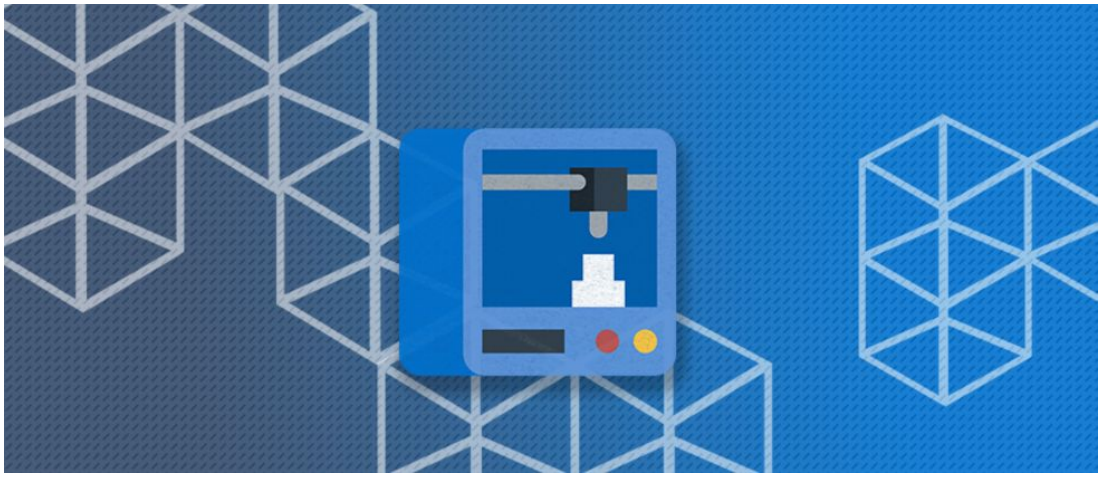
TECHNOLOGY

Incubating the Third Industrial Revolution: The Early History of 3D Printing

by Lee Cooper



3D Printing has captivated the public over recent years, but the history of this technology is already decades old. This post describes the role of 3-D Systems and the UCLA Venture Development Project in the early-stage development of additive manufacturing.

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introduction

Ben-Ner and Siemsen (2017) lay out a compelling case for the vast potential impacts of 3D printing (additive manufacturing), calling it the technology that will usher in the **third industrial revolution**. They go into considerable detail to support their initial claim that "AM is poised to transform many aspects of production, distribution, the supply chain, organizations, and the global economy." But absent from their broad vision is a description of the origins of this disruptive technology. The authors describe the industry as *nascent*:

> *"The adoption of 3D printing will arrive in stages. In the current, nascent, and evolving stage, 3D printing is confined to industrial applications, such as spare parts inventory."*

However, 3D printing was much more nascent 13 years ago, when I encountered the technology in the UCLA Venture Development Project (VDP) in early 2004. We all would gain from a better understanding of the real incubation of this disruptive technology.

3-D Systems and UCLA Venture Development Project

The Venture Development Project (2002 - 2005) at UCLA Anderson did the business due diligence and strategic planning for eighteen companies, mostly startups out of UCLA labs with some projects from Cal Tech and UC Berkeley. The methods were developed in under three years of grants from Intel Corp. specifically focused on strategic planning for disruptive innovations or radically new products. Seventeen of the companies engaged in team projects - typically four MBA students augmented with graduate students from the lab or other bridge people, and the faculty member heading the lab. I ran the VDP through a course called "Strategic Marketing Planning for New Ventures."

The eighteenth project was different. An MBA student, Rajeev Kulkarni, was a product manager at 3-D Systems when he took the course in 2004. He wanted to do a solo, confidential project on his own company. I told him I would expect a team's worth of effort, not a solo act. I insisted because these analyses are laborious to do comprehensively: the team had to find the kernel of the innovation, the best first market for building out the innovation, and fill out the critical-issues grid by investigating political, behavioral,

economic, sociological, and technological issues from the perspective not only of the company, but also how these same factors impact the business ecosystem, and the general infrastructure. All of these factors had to be mapped into Bayesian Networks (Pearl 1986 & 2000) in a dynamic, quantitative, scenario analysis for assessing the likelihood for success (cf. Schwartz 1996). The analyses combined Geoffrey Moore's (1995) *technology adoption life cycle*, Christensen's (1997) writings on the *innovators dilemma*, a little Slywotzky (1996) on *value migration*, and my own work (Cooper 2000) on *strategic planning for radically new products.*

Figure 1. Team assignment from January 2004.

At the time, 3-D Systems Corporation was oriented toward the tool and dye sector with the new SLA system for metal 3D printing. Rajeev saw the complex risk analysis at the heart of the Venture Development Project as an opportunity to determine the best course forward. He developed Bayesian Networks based on his customer and in-company surveys, and used the results to support shifting away from tools and dyes and pivoting to direct manufacture. The company pivoted successfully to a market that fueled further expansion, and Rajeev was promoted to Chief Product Officer, VP at 3-D Systems.

I had helped an earlier student team working on rapid prototyping in a market-assessment or marketing-research class project in the mid-1990s, but can't find any record of that effort. When the VDP came into the picture 3-D Systems made objects like those seen in Figure 2.

Figure 2. 3-D Systems example products circa 2004 with computer mouse for scale.

The *kernel analysis* thinks of disruptive innovations as long leaps across rugged organizational landscapes (Emery and Trist 1965 and Kauffman 1995). The innovation must find enough resources in its local environment to take root and grow, or it dies. Rajeev's Bayesian Network analysis showed a very low (6%) chance of success in the tooling market and a 70% chance of success in the direct manufacturing market, sticking

first to the production of small (< 8”) metal parts. The analysis supporting the pivot was strong enough to convince top management to get behind the young product manager. This is like extending kernel analysis to second-market selection. It also provides strong support against those that would oust the founder. With radical innovation you need to keep the creators central to top decision making. Some CEOs are brought in because of their first-market savvy. Managing the path of disruption benefits from a deeper understanding of the technology/innovation.

Original 3-D Systems Analysis

The putter reflected the new SLA process for metal 3-D printing, which became publically available two months before this VDP project started in January 2004. The shift from photopolymers to metal powders reflects a key point in the evolution of this technology as a basis for something more than rapid prototyping.

So What? Project-Based Learning, Action Research, and Scaling Impact

Recognizing the thoughtful analysis needed to foster disruptive innovation is important in itself. Cooper (2000) impacted at least seventeen companies in addition to 3-D printing industry, my own startup, and served as Travis Kalanick’s introduction to the literature on disruptive innovation - a story for another time. Intel’s support bore fruit. Some of it has just taken a long time to sprout. All of the development is in the public domain.

The VDP is an example of project-based learning - using students’ commitment to a project to put context, meaning, and motivation behind their learning efforts. Teaching kernel analysis, critical-issues analysis, and Bayesian Networks is practically impossible without the extra engagement that real projects engender. As an important byproduct, students learn to work in multidisciplinary teams toward common goals.

Project-based learning has been seen as a major vehicle for closing the skills gap – aligning curricula with the needs of a modern workforce. The Committee for Economic Development (CED 2013) focused mainly of California community colleges and the state

university system. The VDP (cf. Cooper 2004) shows that the benefits of project-based learning also accrue at the highest levels of the post-secondary system. Perhaps highlighting the benefits at the highest levels will help spread the practice.

Action research is another example of project-based learning. Since 2010, I've been involved with encouraging collaborations between NGOs such as Conservation International and MBA teams embarking on capstone projects. These projects supplement the professional staffs of NGOs with the ready-for-market, grad-student talent that would be very difficult to maintain on permanent staff. The enormous opportunity provided by the action-research model is a topic for a future post. Here, I'll just underscore the main issue involved in scaling such efforts.

Big businesses today have transformed themselves into data-driven enterprises partly through the use of enterprise-resource-planning (ERP) systems. ERPs open up the silos that often sub-optimize corporate performance. Seeing all parts of an enterprise as "us," is beneficial, while seeing all outside parties as "them," doesn't fit well with the broad coalitions of small organizations engaged in action-research projects. For action-research efforts the need is for help in forming coalitions, managing projects over time and over changes in personnel, and recording the process and result in a way that we can learn from history. The result of our investigation is that any information system interoperability with #Slack will enable small organizations overcome some of the diseconomies of scale they face. I was one of five gatekeepers that all had to cooperate to connect a project from the Congo Basin Institute to student help in sustainable finance. The right communication channels disintermediate the gatekeepers. It is a marketplace of ideas, interests, and skills. The outputs are projects that, if responsibly managed over time, can have traceable impacts on outcomes. Best practices and evidentiary science come from mining such histories.

Ben-Ner and Siemsen (2017) argue that AM will reduce the minimum efficient scale of a company. This is a continuation of a trend that transformed the computer industry in the last century. Enterprise, in general, will move toward broad collaborations of relatively small organizations, mainly tightly centered on a specialization and covering collectively the whole project needs across organizational boundaries and time. Coase (1937/1952)

asserts that firms grow until it costs more to do a transaction inside than outside. Information networks, the gig economy, and AM signal that smaller is the direction we are going. The NGOs are already there. The issue is how to scale these efforts.

Now, more than ever, we need to make it easier for bottom-up coalitions to get things done. Does anyone know of agents or agencies taking on the central problem of building this fundamental infrastructure? If not, why not?

My next post will be about the university's role in action research (i.e., project-based learning). The third post will look at an entrepreneur's guide to saving the world.

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Author's note: I want to thank Michael Totten for his comments. I also want to thank Rajeev Kulkarni for his cooperation and permission to release his original analyses and supporting materials.

1. Intel Corporation, 1996-97, Project Action: Planning for Radically New Products. Intel Corporation, 1997-98, Planning for Radically New Products (renewed 98-99). Intel equipment provided under the grants was accompanied by software grants from Microsoft.

2. Cooper (2000) won the Marketing Science Institute - H. Paul Root Award for 2000, given by the American Marketing Association to honor the Journal of Marketing article that made the most significant contribution to the advancement of the practice of marketing. I would like to thank David Stewart, then editor of JM, and editorial board of JM for selecting this article as the lead for the January 2000 issue and supporting the article for the MSI award.

3. Strategic Data Corp. was founded in January 2000, and sold to Fox Interactive Media in 2007, cf Cooper 2004.

4. The Bayesian networks were developed in Hugin LT 5.6. I have no idea what has replaced this. The original report and supporting documents are available from the CMR website.

5. Natalie Garrett was an active collaborator evaluating #Slack and the Slack APIs.

6. **https://www.cbi.ucla.edu**

Lee Cooper Follow

Lee Cooper is Professor Emeritus at the UCLA Anderson School of Management. A member of UCLA's faculty since 1969, his research and teaching on competitive analysis and strategic planning have guided teams in the development of disruptive technologies. Cooper led the Venture Development Project (2002-2005) and is currently developing the UCLA Center for Action Research.