Chapter 46

Addressing the "Innovation Gap" for Engineering Education: A Mapping Tool

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Engineering education will increasingly need to incorporate rapid technology development and a societal context, including markets, legal issues, and even policy. It will need to give students the tools to work with early stage technologies and to consider how a technical solution will create value. This paper describes an analytical tool that is based on previous work in engineering design and facilitates the commercialization of emerging technology. An "innovation gap" lies between the creation of a new technology in a university, industry or government laboratory and the formation of technology-based products[8] or plans for new ventures. Crossing that gap requires creating and understanding links among technical, market, intellectual property and business perspectives. Then, the risks, costs and potential social value that characterize a technology-based opportunity can be understood. The Technology Innovation Mapping tool (TIM) supports the conceptually difficult process of building those links and characterizing a specific opportunity that are required for crossing the innovation gap. The tool is a series of maps that help organize that process into three phases focusing on technology, market and iteration, respectively. The tool uses function mapping, (previously applied in engineering design and systematic innovation) to examine both the technology and the market phases. TIM supports the education and practice of technology commercialization stemming from university, industry or government laboratories. The paper provides two examples of technology innovation using the tool.

[8] The term "product" is used broadly in this paper to include services and processes.

INTRODUCTION

The U.S. National Academy of Engineering says, "engineers must know how and when to incorporate social elements into a comprehensive systems analysis of their work. [The landscape of engineering] is not just the nature of a narrow technical challenge but the legal, market, political, etc., landscape and constraints..." [1]. Similarly, technology entrepreneurship, creating the opportunities by which technologies can solve societal problems and create value in the marketplace requires understanding and operating within a legal, market, political, etc. landscape. A series of activities at UT led to the development of courses and competitions that integrate technology entrepreneurship into engineering education. Nichols and Weldon, 1997, discussed the inherent link between engineering and societal interests. They stated, "The practice of engineering does not exist outside the domain of societal interests" [0]. Nichols and Armstrong, 2001 established the inherent link between entrepreneurship and engineering education [3]. The desire to make entrepreneurship a part of engineering education has led to the creation of several education programs at the University of Texas at Austin (UT), which are outlined by Evans and Nichols, 2006 [4]. That paper followed a series of publications that examined the role of innovation and technology entrepreneurship in engineering education [2, 3, 5, 6]. The tool described in this paper grew from the entrepreneurship programming developed at UT and from engineering design methods typically incorporated into undergraduate mechanical engineering programs. The tool is an application of function mapping to better understand and create value from emerging technology. The TIM tool is the method which includes building and refining maps of technologies and their application to markets.

Maps of Functions

Engineers are taught to analyze complex products or technologies by breaking them down into individual functions and the relationships between them. A diagram illustrating the individual functions and their relationships (a function map) is a natural tool to support such an analysis. Function maps have been used in many different fields to analyze brain function [7], business strategy [8], viruses [9], manufactured products [10] and even ideas [11]. The management structure of a company, as an example, has been represented as a network of job functions [12]. The relationships between those functions include collaboration and oversight. Also, the position of a particular job function in such a diagram represents the global status or authority of the job. The president may appear at the top of the diagram.

Engineers use many types of function maps, alternately called function structures, to solve problems. A prevalent type of map used for product design links sub-functions together through their inputs and outputs of signals, material and energy [13]. Genrich Altshuller initiated the development of similar function mapping tools in the development of The Theory of Inventive Problem Solving (TRIZ) [14, 15]. The mapping techniques that support TRIZ use causal links between functions to form function maps. These maps feature positive and negative functions connected by both contributing and counteracting functions. A function might produce or be constructed by both positive and negative functions. As an example, a car produces both rapid conveyance (a positive function) and carbon monoxide (a negative function). The steel frame that contributes to a car's safety also counteracts maneuverability and fuel efficiency.

Function maps support analysis. Their evolution supports synthesis. Engineers create evolving function maps as tools to support the product design process [16]. One point of consensus across many different incarnations of engineering design methods is that the first step is to carefully clarify, or define, or characterize the problem to be solved, or the "customer needs." The task is defined and bounded first. A set of high-level functions is assembled to address the customer needs. These high-level functions are related to one another and systematically reduced to appropriate sub-functions. Later stages of design apply appropriate modules of software or devices or processes to supply these functions and iteratively move toward a detailed product.

For the TIM tool, the purpose is a mapping language that can be learned and implemented very quickly by individuals with very broad backgrounds. Further, the goal is to have a language to represent technical, business and other information in the same map. We outline the details of the TIM tool mapping language below.

Creating Customer Needs

Engineering design is generally about moving from a known market need to a solution and the context of the design activity must be understood. Engineers generally apply function maps to designs and design problems with known customer needs using established technology. An appropriate understanding is built from the knowledge of the engineer or firm and from additional research (if necessary). With an understood set of customer needs, it is also possible for engineers to integrate new technologies into their consideration of possible solutions. The key is to be able to understand a new technology and the work necessary to integrate it into a product or service. In this case existing customer needs lead the consideration of the new technology, a process called "opportunity pull" 815]. The TIM tool is useful for rapidly developing an understanding of the status and capabilities of a new technology and how it might match to the known customer needs.

Engineers working in research laboratories develop new technologies. When these technologies are developed, the best set of customer needs may not have been considered. When the process of commercializing a new technology revolves around a particular technology, the appropriate set of customer needs that represent an opportunity for that technology must be built from an understanding of the technology and possible interconnections with *potential* (as opposed to *existing*) customers. Connections must be built from the technology to a potential market, which is referred to as "capability push" [16]. One way of looking at this situation is that an understanding of customer needs relative to the technology must be created and understood before product design is begun. If one considers technology to simply be technical knowledge, then the situation is more challenging still. Technology (as technical knowledge) can have significant intellectual and academic value; however, technology *per se* has no other inherent social value. To add value (beyond academic and intellectual value), one must create that value. The TIM tool is valuable in support of commercialization that is focused on a particular technology instead of being led by a known set of customer needs.

Technology Commercialization

As quoted by Francis and Bessant [18], Peter Drucker argues that "[prosperity] requires that innovation itself be organized as a **systematic** activity" [18] Jolly describes the process of technology commercialization as a multi-stage iterative process beginning

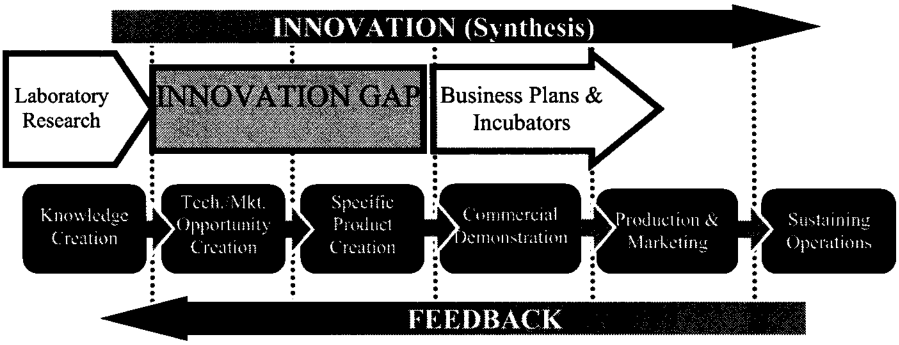

FIGURE 1
THE TECHNOLOGY COMMERCIALIZATION PROCESS
(BASED ON JOLLY [16], ALSO SEE EVANS AND NICHOLS [17])

with the creation of a new unit of scientific knowledge (a technology) and ending in a sustainable product addressing a market need [17]. This process is illustrated by the sequence of boxes in Figure 1. This figure is discussed further in another paper in this volume [19].

Figure 1 also illustrates the gap that exists between technology within a laboratory and one that is connected to a market opportunity. Business plans outline the development of an organization to create value based on products and services. The general assumption in business plans is that those products and services exist. They do not typically outline technology innovation or the development of new products and services (they do not address the innovation gap). Most business plan courses and competitions accommodate business plans based on technology, but the literature provides little guidance for the earlier stage of technology commercialization. As stated above, one must create the value proposition (opportunity based on a technology) before a business plan is prepared and after the technology is created. One must cross the innovation gap. This gap is also present in terms of education about technology commercialization.

Markets for emerging technologies may be discovered, but an opportunity stemming from the application of a technology in a specific market is created. This process of synthesis (creation) leads to several challenges in early stage technology commercialization. First, even the best information available is incomplete. The information is gathered and processed currently, but the creation of value (through business operations or licensing) lies in the future. Risks from technical hurdles or intellectual property cannot be completely known. Second, the actual development status of a new technology is based partly on the application. As an example, if a new paving material was to be commercialized, the technology development necessary for residential sidewalks would differ from runways for heavy aircraft. Third, this is a task that draws from many perspectives and many disciplines. It is challenging to assemble and evaluate information about technology development, intellectual property, potential future market competition, liability, and future value creation potential and make a decision about proceeding to product development or perhaps venture creation.

From Conceptual Challenges to a Tool for Crossing the Innovation Gap

The authors observed three key phases for teams of students (in graduate courses or in preparation for the I2P® competition) crossing the innovation gap: technology focus, market focus and informed iteration [4]. First, teams of students worked to understand their technology and especially what was special about that technology. The technology focus step, similar to the initial step of engineering design, provided the definition and bounding for the task. Then the teams shifted to market research. Finally, with a sense of potential markets and the technology the teams could begin to iterate the best map between the technology features and market needs. From these observations the authors developed a tool based on function mapping as an aid in this three-part process. These function maps have also proven useful to students learning the process of technology innovation and commercialization. In particular, students developed an understanding of their chosen technology and its limitations sooner. Using the tool, students were then able to develop a more comprehensive understanding of potential market applications and how to create market value (or more rapidly eliminate products and technologies from consideration).

Technology commercialization efforts evolve along a similar path: toward maximum value creation with minimum expenditure of resources (time, money, people, etc.). This best-case scenario would be a state of "ideality" [14]. This is another concept that comes from the research behind the development of TRIZ. By considering "ideality" the richest path for synthesis may be considered. Engineering design methods support synthesis, the concept of ideality goes a step further. It provides a direction for that synthesis to follow. In terms of technology commercialization, thinking in terms of value creation and resource expenditure early and continuously helps define the most promising path for commercialization. This concept is integrated into the TIM through a "market context" and is illustrated in the examples that follow.

The following sections outline the application of the tool for two applications. One application represents a straightforward (and relatively simple application) addressing a wood pencil. The second application demonstrates the use of the tool in a more complex environment based on classroom experience.

TIM Function Maps: Rules and Strategies

The TIM has three parts. First, there is a set of rules, or a structure for building a causal function map. Second, there is the concept of a market context. The market context influences the structure and evolution of the map. A changing market or understanding of a market can be echoed in changes to the map. Finally, there is a process for building and refining the map that connects it to the commercialization process. This includes establishing a spatial organization to the map.

Guidelines for Creating a Technology Map

The first step for creating a function map consists of describing the chosen technology in terms of functions and their relationships. The user should consider all of the negative functions and all of the interactions between functions while building the map. Next, the user should begin to organize the map with the application-based (market-based) function (or functions) at the top and the indivisible, technology specific sub-functions at the bottom. Then market context can be addressed with further refinement of the map.

One should note the following points.

1. Functions can be either positive (useful) or negative (harmful).
2. Relationships between functions can be "creating" (producing) or "detracting" (counteracting). The graphical representation of these rules is illustrated in Figure 2.
3. Positive and negative functions can both create and counteract positive and negative functions.

Functions should be described in a few words. The boxes in Figure 2 are kept deliberately small. A larger number of simple functions translate into deeper understanding, better communication of the technology and more opportunities for innovation. The creative freedom allowed by having few rules and guidelines also means that only the simplest examples of maps will be unique. There is a how and why logic to the maps as well. The inbound connections to a box define 'how' that function is created. The outbound connections define 'why' that function is performed. While building the maps it is helpful to ask 'how' and 'why' to check the correct flow of logic and completeness of the map. It is also important to consider 'when'. When each function is performed there may be auxiliary useful and harmful functions performed.

The Importance of Context

The structure of a function map and the words defining its functions reflect the preferences and goals of the user. Taken together with any complementary technology and the influence of a market these considerations form the context of the map. The context is critical for mapping emerging technologies. A technology might convert rotational energy into electrical energy. The core function might be defined in purely technical terms as "10V at 0.1amp." This single watt of power might be defined as "provide 600J of electrical energy over 10 minutes", "recharge battery in 10 minutes" or "recharge camera in 10 minutes" or "recharge digital SLR in 10 minutes." These definitions of the same function form a progression from a purely technical function to one that is focused on and defined by a certain market. The market context is different for each of these definitions and suggests a progression from a technology to the techno-market understanding that occurs while crossing the innovation gap. The map, as will be shown, evolves with a changing target market or even a changing understanding of a target market.

The initial focus of the TIM is to map technology. Some types of functions are not influenced significantly by changing market context. Market context would not significantly influence the definitions of the functions associated with actually converting

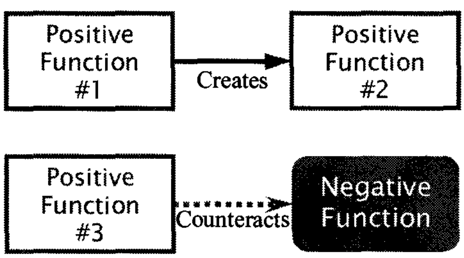

FIGURE 2
GRAPHICAL ELEMENTS FOR BUILDING A CAUSAL FUNCTION MAP

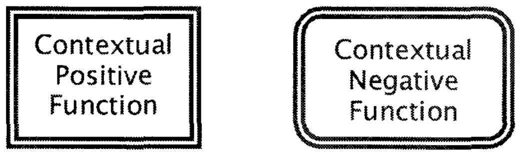

FIGURE 3
GRAPHICAL ELEMENTS FOR CONTEXT-BASED FUNCTIONS

rotational energy to electricity in the previous paragraph. One can imagine a type of hierarchy to function maps of technologies where the ultimate, central function is at the top and the constituent elements or sub-functions are organized below. This hierarchy is organized by the authors into three sections: I) The indivisible sub-functions, II) the intermediate region (where most of the interactions and main functions are located) and III) the functions that are influenced by market context.

Other functions are provided by or reside in the context of a technology, or outside the defined system boundary. An important function may not be specifically part of the technology being mapped. As an example, one might model cooking an egg in a pan. The heat from the stove is an important element, but could be considered as part of the context of the pan and egg technology to be mapped. Functions that are important to a map, but not a part of the system being mapped are represented in a special way in the TIM, as illustrated in Figure 3. These can be seen as providing a function conduit from the context to the technology being modeled.

Refinement and Organization

Function mapping within the TIM is an iterative process that begins with a focus on the technology *per se* and evolves to include market context. The authors suggest that the initial context should be stripped of market considerations, leading to consideration of the concept in the abstract which encourages an expanded design space. That is, definitions of functions should not initially contain application language: "1 Watt" is preferred to "charge battery." "Design fixation" in engineering design takes place when a decision on a particular solution is made early in the design process (due to the consideration of previous designs) and blocks the consideration of other promising solutions (thereby limiting or eliminating later design options). Busby and Lloyd, 1999, describe this in terms of a search process that can "suffer from being too narrowly focused and having too much inertia" [20]. Describing the technology without an application bias facilitates the consideration of additional applications. Design fixation in this case might be called "application fixation" which similarly limits innovation.

EXAMPLE: THE WOOD PENCIL

Using the language and process outlined above, one may create a function map for a wood pencil. This is a similar activity to the various methods of function mapping that are used routinely in engineering design. In this way it is a good stepping stone from engineering design methods to the process of crossing the innovation gap. This mapping clearly does not involve new technology development. It does, however, provide a good example (or case study) for exploring the innovative insights function mapping can support and emphasizes the importance of context (including the market application) in the creation and evolution of a function map within the TIM process.

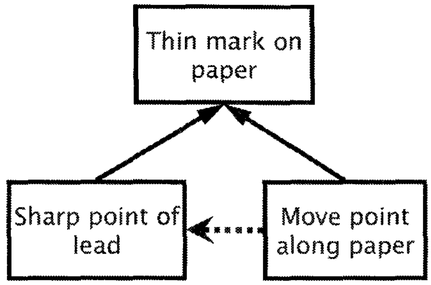

FIGURE 4
PRELIMINARY FUNCTION MAP OF A WOOD PENCIL

Where to Start

One could begin the map in several ways. The starting point could be the constituent pieces (the wood, the lead material and paper). It is important to consider that there is preference and context associated with the choice of wood, lead and paper. This choice implies a specific writing instrument and marking paper. The point here is to work through an easily understood example. It is also possible to begin from a known core or ultimate function. The discussion here is organized by building from a core function, making a thin mark on paper. The word 'thin' in the previous sentence is important. It is based in the context of the problem. "Thin" is the *desired* feature of the mark, possibly being driven by the market application for the technology. The addition of it influences the creation of the function map.

Building the Map

If the core function is to make a thin mark, then what sub-functions are needed? (If the map was started from the constituent pieces the question would be, what functions do these pieces provide individually and in combination?) As seen in Figure 4, one may define how the thin mark is produced with two sub-functions which form a preliminary functional map:

- One needs a sharp point of lead and
- One needs to move that point along the surface of the paper. (Moving the point along the paper, as experts in this technology know, dulls the point of lead.)

The dotted arrow in Figure 4 indicates that moving the point along the paper counteracts the sharp point of lead. This feature might not be added to the map without the word 'thin' in the core function of the technology. The other arrows indicate that the sharp point of lead and moving the point along the paper jointly produce the thin mark on paper.

Before building additional sub-functions into the preliminary map for the wood pencil, consider the concept of market context. When a wood pencil is used to write or draw it is possible that a thin mark might be placed in a desired location, or it might be in the wrong place. These possibilities are illustrated in Figure 5, which includes information about the technology and a market application for the technology. Boxes discussed in a previous diagram are shown in grey. This convention will be followed throughout the paper for clarity. Jolly 1997, describes the activity of "deliberately

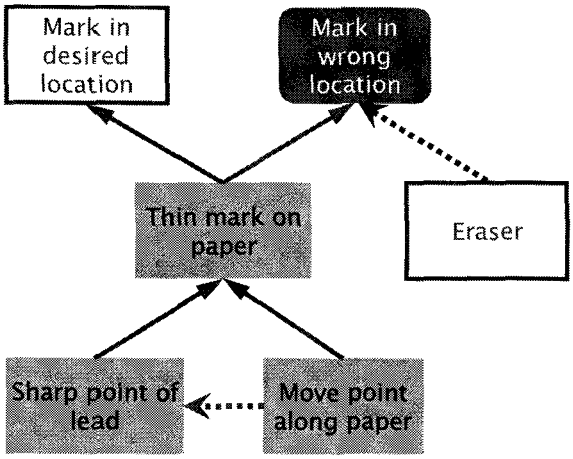

FIGURE 5
PRELIMINARY WOOD PENCIL MAP WITH MARKET-BASED FUNCTIONS

alternating your focus between the technology and the market" as the best means of facilitating a "breakthrough" [17]. Function analysis naturally facilitates this shift in focus. If one was not an expert in the wood pencil technology, Figure 5 might facilitate the addition of an eraser (to counteract marks applied in the wrong place) as a new innovation. As introduced above, the market context influences some functions and not others. Here it applies to the top of the diagram. How the mark is made *per se* is not influenced by the market. This element of TIM is revisited in terms of the example in the next section of the paper.

We examine the wood pencil further for applications not requiring an eraser. The map in Figure 4 may be further developed by looking at each sub-function and considering functions necessary to produce it. A sharp point of lead requires thin lead material and a means of making it sharp. Moving the point along the paper requires support for the lead material and some type of grip for a person to hold. These sub-maps are illustrated in Figure 6. The assumption of thin lead and support of that lead come

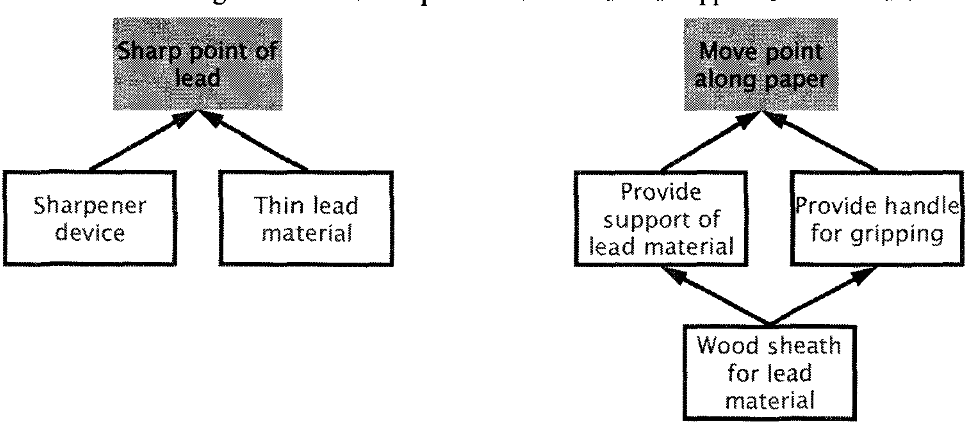

FIGURE 6
SUB-FUNCTIONS FOR "SHARP POINT OF LEAD" AND "MOVE POINT ALONG PAPER"

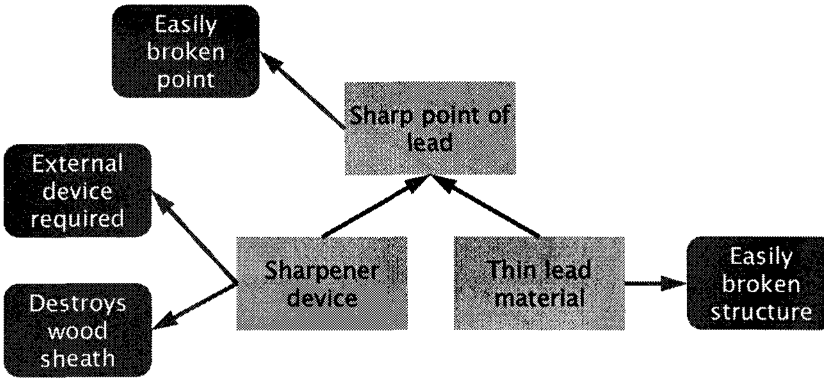

FIGURE 7
HARMFUL FUNCTIONS ASSOCIATED WITH "SHARP POINT OF LEAD"

from this example being driven by an actual artifact, rather than a new or emerging technology. If you simply had a thick, sharpened cylinder of lead as a pencil neither of these features of the map would exist. However, there would also be negative functions associated with a thick cylinder of lead material. The lead would have a relatively high cost and using the technology would produce blackened fingers which would point to the innovation of a thinner lead with wood support.

Following from the consideration of blackened fingers in the previous paragraph, it is important to fully consider useful and harmful functions associated with the technology and both complementary and counteracting relationships between functions. A pencil sharpener is an external device and it destroys the wood of the pencil. Sharp lead points are easily broken. Pencils create black dust. These negative or harmful functions may be connected to the sub-function diagrams shown in Figure 6. The new sub-function diagrams are illustrated by Figure 7 and Figure 8.

Figure 4, Figure 7 and Figure 8 may be connected together into a single function map representing the wood pencil technology. The combined function map is illustrated in Figure 9. It may be easy to consider the function of a pencil and its shortcomings

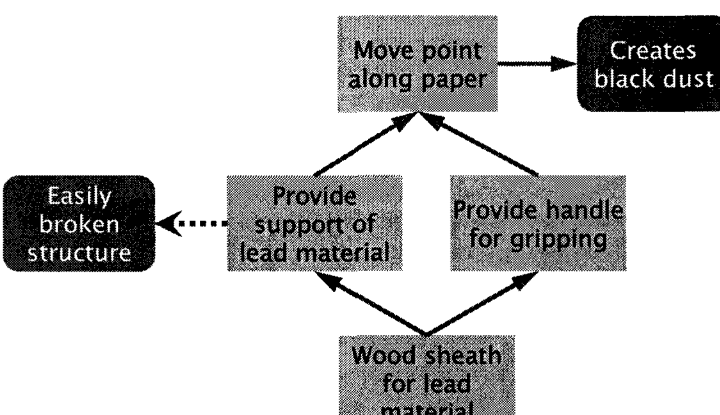

FIGURE 8
HARMFUL FUNCTIONS ASSOCIATED WITH "MOVE POINT ALONG PAPER"

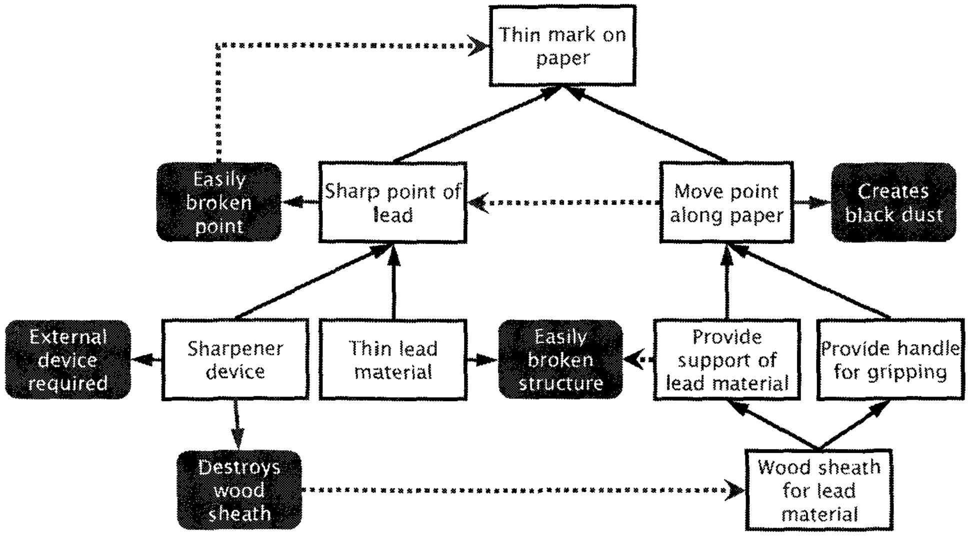

FIGURE 9
FULL FUNCTION MAP OF WOOD PENCIL TECHNOLOGY

without this map. However the map brings all of the functions and their relationships together into a single diagram. It is easy to focus on one negative function or on more complex systems of functions. TIM facilitates additional development of the technology or consideration of a market where the negative functions might be redefined or simply of lesser importance.

Map Evolution and Commercialization

Function maps of technologies are working documents. The function "move point along paper" might be amended to read "removal of lead on paper". This change would facilitate some changes in the diagram that more accurately represent all of the functions of the system including representing a writing surface (paper) as a separate function. Figure 10 illustrates this refined map. One of the refinements represented in Figure 10 is the spatial organization step within TIM. The fundamental elements of the technology, lead, wood and paper are moved to the bottom of the diagram while the core function of the technology remains at the top. There are two functions in the new diagram that are defined as driven by the context of the technology; the force from the hand (similar to the heat from the stove in the egg cooking example above) and the sharpener device.

The value of going through this process is highlighted when further development of the wood pencil technology is considered. An ideal pencil would perform the core function without the negative functions and without the counteraction of positive functions. The technology innovation represented by mechanical pencils is a step in this direction toward "ideality." Mechanical pencils retain the core function of the wood pencil but eliminate the "external device required" while also removing the negative influences on the sharp point by the "removal of lead on paper" and on the wood sheath by the "sharpener device." In other words, the function representation of the wood pencil supports a complete understanding of the technology and how it can be developed in a particular context. Innovations change the map and support additional innovations. The wood pencil is a technology intimately coupled with a particular application. It is also a

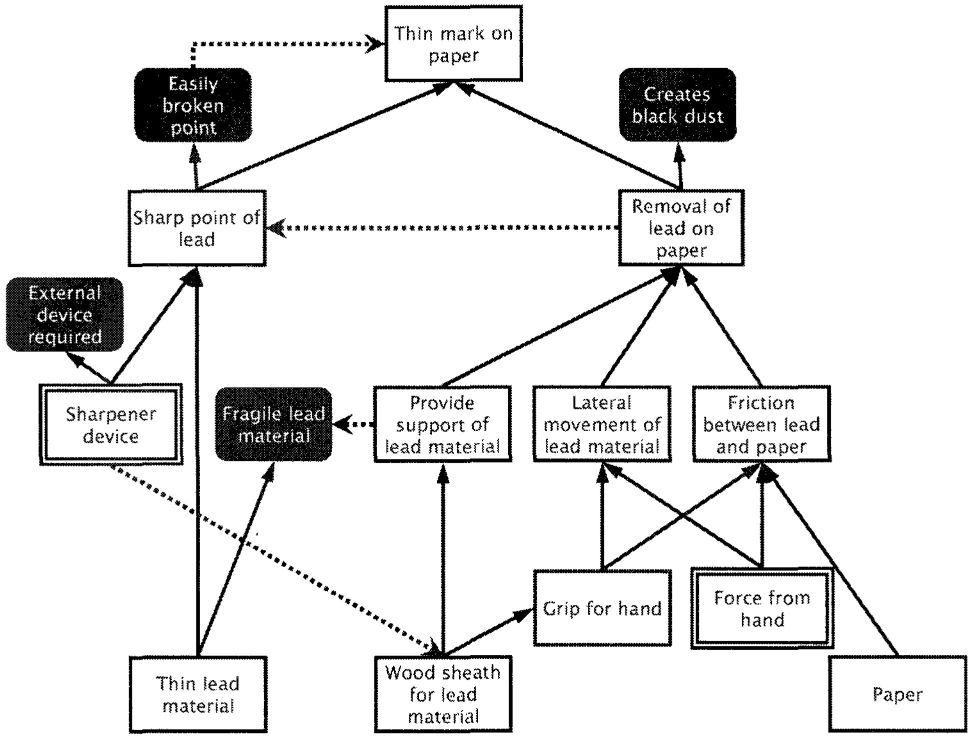

FIGURE 10
REFINED MAP OF WOOD PENCIL TECHNOLOGY

product. The next example illustrates the effect of the tool for crossing the innovation gap, where the specific market and a defined product are unknown.

CROSSING THE INNOVATION GAP: THE NANOTAXI TECHNOLOGY

A team of students, Luz Cristal Glangchai, Abiola Ajetunmobi, Jakub Felkl, Shreyas Rajasekhara, Adrian Eissler, Rohin Mukhi, took the Enterprise of Technology Graduate course in 2006 [4, 5]. They applied the TIM tool to their class project. Their experiences and innovation illustrate the support the tool provides for education and for commercializing emerging technology. The key lessons in this section follow from the commercialization challenges outlined in the introduction of the paper. The example of the pencil illustrated the effect of market considerations on the function map of a technology. With this example it is possible to examine more fully how building a function map facilitates rapid comprehension of a new technology and forming connections between the features of a technology and the specific needs and characteristics of a market.

Cristal Glangchai, a doctoral student in biomedical engineering and co-inventor of a nano-scale cellular delivery technology enrolled in the course hoping to analyze the commercialization potential of her technology. On the first day of class, she met Abiola Ajetunmobi, Jakub Felkl, Shreyas Rajasekhara, Adrian Eissler and Rohin Mukhi and formed a team for the course. The team members learned about and contributed to technology commercialization.

The NanoTaxi team progressed through the Technology Phase, Market Phase and Iteration Phase of crossing the "innovation gap." Teams from previous semesters of the EOT course also progressed through these stages without the tool. The author's comparison of the experiences of the NanoTaxi team with teams from earlier illustrates how a map may be created for an emerging technology, how TIM supports emerging technology commercialization and finally the value of the tool from an educational perspective.

The Technology Phase

At the beginning of the course only Ms. Glangchai had technology subject matter expertise. The technology spans biomedical and nano-manufacturing technologies. Researchers had imagined many potential applications for the technology (cancer treatment, pain management, medical imaging, etc.), but had not focused on an application (balancing risks, costs and potential value creation). The technology had been proven as a laboratory concept, but not tested in actual organisms. The team expertise and early stage of the technology development created special challenges related to team participation in a complex, laboratory technology and to an ability to create an appropriately detailed connection to a market.

The team created an initial map of their technology within the first two weeks of the class. It includes "medicine," "purification" and "effective imaging" as application-specific functions. The core function attached to each of these was a "stimulus-based response." That was then attached to a function called "chip." It has many pieces and little overall organization. It is difficult to understand what the technology is from the map. And, it is a great beginning. The map neatly represents the teams' understanding of the technology at the beginning of the semester. The team could not be expected to understand their technology immediately. More importantly, the team was considering many different elements of the technology and the context of their technology immediately and in parallel. Even the initial map showed that the team was ahead of their contemporaries in previous semesters.

Shortly after preparing their initial map, they could describe their technology in a single sentence. "Our technology utilizes nano-imprinting techniques in a cleanroom environment to fabricate injectable disease-responsive nano-containers with a 'lid' that can effectively sense a physiological stimulus and consequently release therapeutic agents stored within them at a target site inside the body." It is laden with technical terms, but does capture their technology. This single sentence is shorter and much simpler than Ms. Glangchai's initial description of the technology on the first day of class. For the other students it represents a rapidly developed understanding of the technology. Their map changed quickly as well. After describing their technology in a single sentence they began to understand the functions of the technology. Figure 11, a section of a larger map, illustrates their advancing understanding. It is an important figure since it contains only the physical elements that uniquely a part of the technology. It is a more concise representation of what their technology actually is, without application specific terminology. This is a platform for considering many different possible applications. The diagram may be compared to the one-sentence technology description above. Without specific research into the effect of the maps, it is difficult to discern causality, but there is

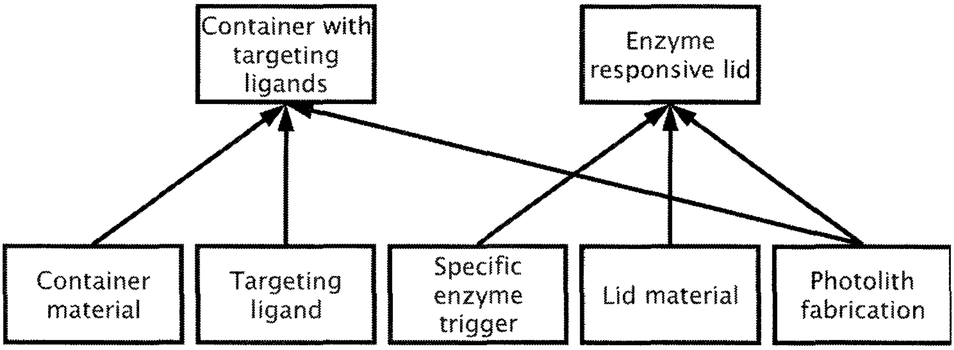

FIGURE 11
CORE FUNCTIONS OF THE NANOTAXI TECHNOLOGY

correlation between the changing map and the evolving team understanding. Further, in previous semesters teams struggled for several additional weeks to distill their technology to its fundamental elements. In comparison to the authors observations of teams from previous semesters the NanoTaxi team understood what their technology was, as a team, earlier and more comprehensively.

The Market Phase

As the team began to create a focused understanding of their technology the course material shifted to basic marketing and intellectual property topics. The team returned to a focus on cellular delivery and was able to build this emphasis into their evolving function map. Figure 12 shows the functions immediately supported by the core elements of the technology in Figure 11.

After making the decision to focus on cell delivery, The NanoTaxi team submitted a market report that assessed the potential for pain management, cancer treatment and

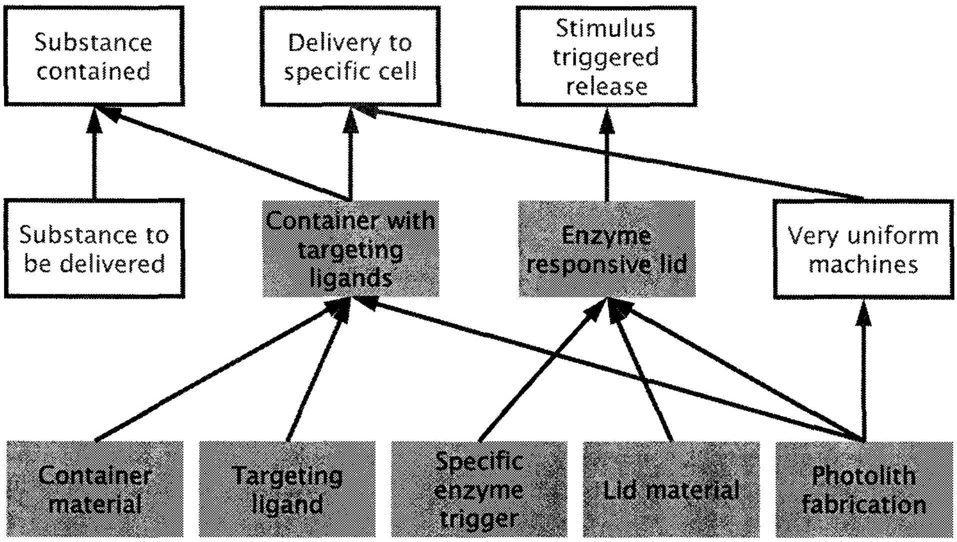

FIGURE 12
CELLULAR DELIVERY FUNCTIONS

medical imaging. They were able to analyze how their technology would deliver benefits to each of these markets by adding market specific functions to the map shown in Figure 12. Figure 13 is an example of these additional market-specific functions. It is relatively easy to consider functions that *might* be useful in a particular market. The early market reports in the class often contained technology capabilities that might be useful. Understanding what would be *valued* in a market is challenging. The NanoTaxi report emphasized value. Their analysis included more market information relative to previous semesters, including primary research. The use of the maps changed their focus to finding problems in the market instead of imagining possible capabilities of the technology. They chose to focus on cancer treatment and were then able to add functions specific to that market as shown in Figure 13.

At a casual glance Figure 13 may seem complex, similar to final map of the wood pencil above. Its three main regions, top, middle and bottom, however, describe the technology in a way that is valuable for the task of understanding possible commercialization routes. From the first map several weeks before, the organization, context and even the words used in this map are dramatically different. Terms such as "adequate" or "effective" are replaced with measurable features. The top of the map features the desired functions defined by the market context. The constituent elements of the technology are organized across the bottom of the map. At the same time the team further refined their technology understanding and developed a sense of how features of the technology may be defined in terms of market needs.

The function maps in Figures 11, 12 and 13 have not included "negative" functions

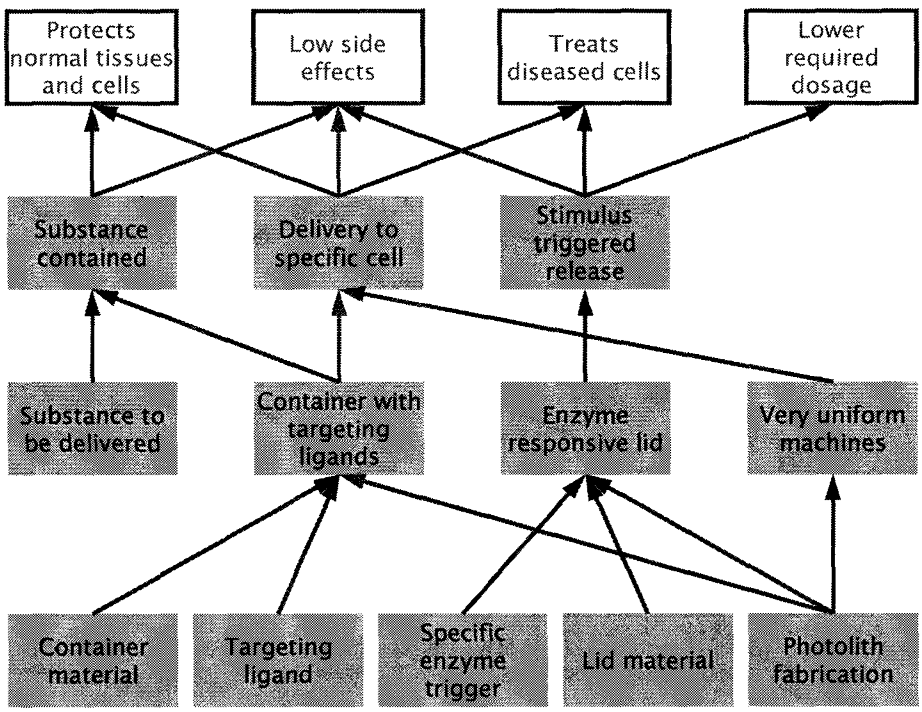

FIGURE 13
CANCER TREATMENT FUNCTIONS

to support the discussion. However they were also a part of each map submitted by the team. The other element not seen in the diagrams above are functions provided by external elements. The team realized that although semiconductor fabrication techniques were essential to their value proposition they were not a part of their technology. Figure 14 illustrates the full map including "negative" functions.

The "negative" functions in Figure 14 are interconnected with the "positive" functions indicating need for significant additional research for their early-stage technology to address each of these potential problems. The negative functions can help organize a plan for further technology development. It is important to consider that ideality for a map between a technology and a market goes beyond the functions included in Figure 14. It is about maximizing value creation and minimizing development costs. Pursuing the greatest value creation with the least development costs could be pursued through seeking alternate markets or through new capabilities created during additional research.

The NanoTaxi team's use of TIM facilitated rapid progress toward the Iteration Phase of Innovation Gap. The next steps would be to build into the map the series of research, clinical trials, manufacturing and other tasks needed to actually deliver treatment to a cancer patient. These additional functions would support understanding the risks and costs associated with commercializing this technology. Those costs could then be compared with the value that could be created in the market to assess the economic viability of this plan. Subsequent papers provide additional discussion about the TIM tool. The maps shown in this discussion facilitate several important insights. First, the TIM tool organizes the examination of emerging technology into a systematic process. The tool encourages a progression from understanding the technology, to understanding how it would create value in a market. Only after these considerations would the details of development costs and other risks need to be considered. More specifically, The NanoTaxi team clearly identified how the technology connected with important needs in

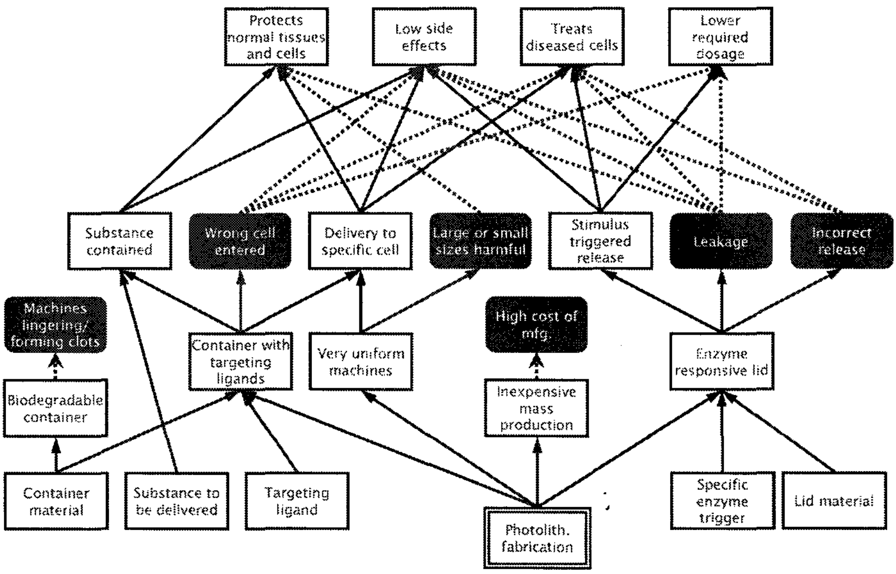

FIGURE 14

FINAL NANOTAXI TECHNOLOGY MAP: INCLUDING HARMFUL FUNCTIONS the cancer treatment market. They recognized what was really special about their technology and what was context (such as the manufacturing method). They created new knowledge about how the technology could be used to solve a problem in the marketplace in an economically viable way. The simplicity of their final technology description is one example of their progress. "Our technology is a nano-fabricated drug delivery device that selectively releases toxic drugs to specific diseased sites in the body." The discussion of the market that they prepared was outlined by the four functions found at the top of the diagram. Ultimately, they created an award-winning opportunity for an emerging technology

CONCLUSIONS

In this paper we have described a tool to help navigate an innovation gap that exists in early stages of the technology commercialization process. The tool was created based on function mapping tools that have been previously used to support of engineering design and other synthesis activities. This Technology Innovation Mapping tool represents a step toward organizing the work within these early stages of technology commercialization into a systematic process. Further work is directed toward this goal.

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