Interdisciplinary Design: The need for collaboration to foster technological innovation to create competitive and sustainable products.

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Abstract

This paper explores an integral relationship between industrial design, advanced technologies, science, economy, and the environment to realize a logical trajectory for the future of product design. Through an investigation of current literature, key aspects and critical factors of interdisciplinary collaborative work are explored. By realizing the benefits and obstacles, this paper suggests a framework in which scientists, engineers, and designers can work together successfully to create innovative solutions for product design. The paper discusses the possibilities of material synthesis through the scientific field of biomimetics. It also suggests that the Industrial designer's role must evolve into a position of project facilitator and communicator. To conclude, this paper mentions technologies utilized currently in this fashion and ideas are proposed to further guide this framework.

Keywords

Synthetic Biology, Interdisciplinary Design, Cross-Functional Teams, Biomimetics, Industrial Design, Product Design, Advanced Technology, Sustainability.

As the world's population grows and and the amount of resources that are available to be extracted from the earth does not, there is going to be an inevitable and drastic difference in the supply and demand of energy and resource for product manufacturing in the years to come. For example, "conventional crude oil production in the United States is forecast to terminate by about 2090, and world production will be close to exhaustion by 2100" (Edwards, 1997). This threatens the environment, the global economy and in turn social well-being. Either consumption and production of industrial and consumer goods cease or we must find new ways to produce or to create materials and technologies. The former is unlikely to happen. The latter is what is probable and is in flux. As material scarcity threatens the world and its inhabitants, environmentally incompatible material production processes threaten them also. The world's industrial nations must find solutions to reduce the burden that is being placed on our earth through the removal of finite stores of resources and the creation of harmful industrial effluents.

This paper is concerned with the role that scientists, engineers, and designers will have in finding solutions to the problematic relationship between consumption and resources, environment and production. Not only is this paper concerned with these individual disciplines, it is primarily concerned with establishing a framework for these diverse schools of thought to interact in a cooperative fashion to reach the solutions necessary to address the problem effectively. Interdisciplinary approaches to knowledge creation are crucial to solving problems of this magnitude. Only through the synergy of disparate schools of thought will the world render the creative solutions necessary. Interdisciplinary work between scientists, industrial designers, and engineers holds great potential for dealing with environmental issues concerning new product development. Biomimetics, a broad scientific approach, has great potential to bring dissimilar schools of thought together to form such solutions.

Overview

This paper begins with a literary overview of works by relevant scholars. This investigation explores:

1) How an interdisciplinary design approach is paramount to finding innovative solutions.
2) How critical factors of group dynamics and theoretical knowledge about interpersonal communication foster such research.
3) How interdisciplinary work between designers, engineers and scientists, representing the most advanced technologies plays an integral role in imagining and engineering the best product solutions.

Following the literary overview, in section 2, is a discussion of the findings. Section 3, based on these findings, will suggest solutions, a framework for future interdisciplinary design, and possible interdisciplinary trajectories.

Key Aspects of Interdisciplinary Design Collaboration

Combining disparate schools of thought is crucial when dealing with complex problems. We have drawn from several academics who support this notion. There are a few terms that are used to define these types of teams: these include interdisciplinary teams, multidisciplinary teams, and cross-function teams. For the purposes of this paper these three terms will be used loosely. Each is similar in the sense that they define teams that have a relationship within an organization. What is most important and shared among these classifications is the sense of team. Holland and Gomes (as cited in Cohen & Baley, 1997) define it as:

> A team is a collection of individuals who are interdependent in their tasks, who share responsibility for outcomes, who see themselves and who are seen by others as an intact social entity embedded in one or more larger social systems, and who manage their relationships across organizational boundaries" (Holland, Gaston & Gomes, 2000).

This paper is most concerned with concepts of togetherness and common goals. These are critical factors that are the crux of collaboration towards an agreed upon end. Other critical factors will be discussed in the following section.

An interdisciplinary project according to Professor and Director of the School of Industrial Design, Carleton University, T. Garvey, (2009) consists of disparate disciplines or professions involved in tackling a problem with the application of new knowledge. Each is an equal stakeholder. The difference according to him between interdisciplinary and multidisciplinary is that the latter does not integrate the disciplines. Each discipline is responsible for individual results and the knowledge represented will change contingent to the proposed challenge.

Many academic institutions and commercial enterprises are currently practicing some form of interdisciplinary learning approach. In Canada, Carleton University presently is in its second year of its MDes program which focuses on interdisciplinary design research. In the United States, Stanford and MIT have their specific brand of interdisciplinary design research. Delft Technological Institute, in The Netherlands, also has a program that focuses on strategic design planning, heavily slanted toward multidisciplinarity. The transnational corporation Nortel, in its hey-day, had a faction of its organization called Design Interpretive delegated to cross-functional product design development that helped pave the way for this type of thinking (Frankel & Tsuji, 2005). These organizations have realized the need for collaboration among disparate disciplines to come up with innovative ideas. Academics discussing the subject suggest it is crucial. Relevant to the context of this paper Persson and Warell (2002) not only suggest there is a need for integration of industrial design and engineering functions but also assert that it is a prerequisite to render innovative solutions that will successfully meet market and environmental needs.

Benefits of Cross-Functional Teamwork

Nations are built from the contribution of many. Governments, Hollywood film crews and championship baseball teams only function due to the contribution of many participants in which strengths fill in for others' areas of weakness. For collaboration in the area of product design the requirements are the same. Sonnenwald (1996) suggests participation in group design efforts from different domain representatives is widely accepted as a prudent approach to developing innovative and competitive products while at the same time reducing costs. Furthermore, the benefits to this type of organization are plentiful. Holland et al. (2000) attribute nine benefits to cross-functional teams. Increased speed is perhaps the most important. When dealing with competitive markets this benefit cannot be overlooked. A teams' ability to deal with complexity is also important. When taking into consideration the complexity that environmental and economic issues have, which this paper is concerned with, simple solutions are not likely. Professor Bjarki Hallgrimsson (personal communication, November 18, 2009) claims interdisciplinary or cross-functional approaches increase in importance as a project increases in its complexity. When dealing with such complexity, single points of contact, informational quality, and learning within the organization--so everybody is 'on the same page'--are pertinent to the teams success (Holland et al, 2000). Holland et al. (2000) attributes these three benefits to cross-functional team approaches. A fostered intrapreneurial and entrepreneurial culture within the organization is important. This supports healthy competition integral to innovation which will extend beyond the walls of the particular organization. Another benefit suggest by Holland et al. (2000) is that of motivation. Whether it is team or individual motivation it can be encouraged through a competitive organization. Enhanced creativity and customer focus are the last two benefits suggested by Holland et al. (2000). Both are important to the scope of this paper.

Obstacles Confronting the Collaborative Design Approach

As benefits are apparent, there are hurdles to interdisciplinary design teams that can vitiate successful outcomes. The literature recognizes communication problems as a major issue to be dealt with in collaborative design teams. Berryman (2002) recognizes that there are often daunting hurdles faced by interdisciplinary teams and one of them is language.

It is currently recognized within the field of interdisciplinary design research that there should be a unified body of knowledge (Love, 2002) that fosters an understanding for all disciplines that participate. This further supports the issues of language barriers facing interdisciplinary design team efforts. Unifying a body of knowledge in this field is not as easy as one may think. As the field grows in its scope and more disciplines participate in this type of organization, it becomes difficult to create vernacular that can support such an endeavor (Love, 2002). The issues that can arise due to this lack of a unified body include theoretical conflicts between researchers, lack of theory validation, unclear scope, and an inability for new researchers to identify sound epistemology (Love, 2002).

Chiu (2002) recognizes four areas of communication, which can lead to less than the desired effect. These include:

I) The media problem in which design information must be conveyed properly.
II) The semantic problem where symbol transmission is lost due to noise.
III) The performance problem that deals with issues in receiving intended information and reaction of the receiver as the sender wished.
IV) The organizational problem where information is lost or reduced in integrity through its travel within the hierarchy i.e. 'broken telephone'.

The larger the group the more intricate the hierarchy and thus the more chances that information is altered. This challenge of communication effectiveness is not the same significant issue when communicating face-to-face. Usually it is not the lack of know-how or expertise that creates the problem. It is the non-representation of information that is lost. Safoutin & Thurston (1993) refer to this as failure in design mechanisms. Many design failures are attributable to commonly understood mechanisms, suggesting that they are not due to a real lack of expertise within an interdisciplinary design team but rather to communication errors at key decision points (Safoutin & Thurston, 1993).

Hurdles faced by interdisciplinary design teams cannot be attributed to communication functions alone. Sonnenwald (1996) claims "knowledge exploration can be difficult for design participants." Unique experiences and confidence in ones' skill can lead to what Sonnenwald calls "contested collaboration." This happens when individual perceptions vary and participants challenge or contest another's contribution.

Holland et al. (2000) identifies six areas that hinder cross-functional efforts. These include conflicting organizational goals, competition for resources, overlapping responsibilities, conflicting personal goals, no clear direction or priorities, and lack of co-operation. Kim and Kang (2008) (as cited in Wall & Lepsinger, 1994) also identify obstacles that overlap and confirm what other researchers are finding.

> The key issue, affecting 80%...was the tension that exists between team goals and functional priorities, surfacing in the form of: conflicting organizational goals; competition of resources; overlapping responsibilities; conflicting personal goals; a lack of clear direction or priorities; and a lack of cooperation (Kim & Kang, 2008).

Safoutin and Thurston (as cited in Steiner, 1972) add that "process loss always occurs in real groups, and stems from informational, behavioral, and organizational factors that impede the application of existing group resources to the problem at hand."

Group dynamics have not changed much over the last few decades. This paper assumes that is because people, for the most part, have stayed the same. However, it is the application of this honed knowledge about interdisciplinary teams towards solving complex issues that is the focus of this paper. Through this and other investigations, this field of study comes closer to pinpointing the critical factors that increase the chances of successful interdisciplinary design efforts.

Critical Factors Affecting Collaborative Approaches

There is much to learn about interdisciplinary approaches to knowledge creation. Although it is a popular topic among academics, there is still a lack of insight into what is critical to the success of teams comprised of dissimilar disciplines. Holland et al. (2000) suggest that “the emergence of cross-functional teams is one of the most dramatic recent trends in organizational design.” Although, it seems interdisciplinary practice is exceeding the amount of scholarly research, There is plenty of room for error within organizations that are intending to successfully implement these types of design teams. As interdisciplinary design research and product development is crucial to solving complex issues, these teams do not always function as they should. Noted above are hurdles teams face on a regular basis. To excise these impediments researchers suggest factors that teams must possess that are critical to successful outcomes. As failures in communication are common and are what is most responsible for negative outcomes, quality communication is one of these critical factors. Dr. W. Wehrspann (2009) asserts personal relationships do not operate properly without effective communication. This being so, it is unlikely that business relationships within a complex organization will operate succinctly. Holland et al. (2000) and Frankel and Tsuji (2005) discuss the critical factors leading to successful interdisciplinary or cross-functional design team efforts. Their findings among others are reviewed below.

Management

Holland et al. (2000) suggest quality management, shared goals, quality communication, organizational structure, creative output, constructive conflict, psychosocial traits, and resource availability as some of the critical factors. This paper is concerned with these because they best reflect its scope. “The fish stinks from the head down,'' is a common chide on bureaucracy. It stresses the need for good leadership. At the tip of the organizational iceberg, leaders or managers must perform functions successfully to assure other critical factors are met. Shared goals by disparate members are possible but it can be better fostered through quality management. Berryman (2002) suggests that collaboration can be a struggle. However, this struggle can be effectively managed “with a solid strategy involving basic tenets of good project management” (Berryman, 2002). The organizational structure is also quite dependent on the management. Holland et al. (2000) suggest leaders to be educators and communication facilitators. This will allow for a flexible but structured organization in which roles are not rigid and responsibilities do not overlap. If this is not so, innovation qualities are greatly lost. As innovation is important, so too is creativity. The literature review suggests there is a strong co-dependent relationship between the two. Dankbaar and Vissers (2002) suggest innovation is supported by an organic structure and creativity is fostered by group autonomy. Within an organizational structure, which allows for fluidity of information, creativity is spawned and creativity begets innovation.

Social Factors

Often people attempt to avoid conflict. This investigation suggests that there is functional conflict and dysfunctional conflict (Holland et al. 2000). Conflict cannot be avoided. However, there are positive conflict outcomes. For this to work, ideas must be expressed freely and team members must be willing accept constructive criticism. This relies heavily on the psychosocial traits of the team members. It is suggested that embracing characteristics such as empathy, active listening, overall emotional intelligence, and “a sense of humor as a group...to shed stress” (Frankel & Tsuji, 2005), can put a positive spin on conflict. Though each individual’s personality traits affect the overall psychosocial dynamic of the group, it is up to management to support an organizational structure that develops a team which is greater than the sum of its parts.

Within Nortel's Design Interpretive team, Frankel and Tsuji (2005) explain the need for self-motivated members who carry mutual respect for one another. They suggest an organization that functions horizontally rather than a vertical hierarchy. Their investigation supports notions about sensitivity to constructive criticism. Team members must also be experts and all should be mutually responsible for the outcome.

Resources

Holland et al. (2000) mention resources as a critical factor. Not enough resources and a team cannot have the appropriate organizational structure. Members take on too many roles and have too much responsibility. This can affect team tenure (Dankbaar & Vissers, 2002) and spoil overall outcomes. It must be noted that though there is lack of resources, at times it can spur innovation.

The above investigation mentions some of the significant factors that would contribute to the successful outcome of interdisciplinary teams. What is noted here, is that all teams cannot function using a universal template. Critical factors will depend on complexity and nuances of the project itself.

Interdisciplinary Teams and Advanced Technology

The previous sections have discussed ways to support interdisciplinary design efforts and outlined what is needed to increase chances of succeeding. We now review interdisciplinary approaches within the context of advanced technology. The professions that most concern the scope of this paper are industrial design, engineering, and science. Each plays an important role in finding solutions for prescribed issues for this paper. The industrial designer is responsible for vision and communication. Scientists represent the most advanced technologies. The engineer's role is the application of that technology. Specifically within engineering and science this investigation is interested in the roles of material engineers, chemists, biologists, physicists, and environmental scientists.

As designers who are part of an international community, there is a realization that greater and more complex issues are arising in new product development with respect to resource availability, environmental health, economic stability and sociocultural environments. Frances Bronet states,

> There is a growing recognition that significant challenges await us in the years ahead if the nation is to compete successfully in a highly competitive global economy, while also seeking to share social well-being and restore the natural environment upon which all life and technology depends (Bronet, 2003).

The designer's role is changing to take on more responsibility. This responsibility lies in envisioning future products and facilitating the disciplines that are necessary for developing advanced product solutions. This requires an industrial designer to be well-versed within their own discipline, requiring artistic and engineering abilities, and have a deep understanding of the sciences and economics. Having a degree in Communications would not detract from a designers ability.

Interdisciplinary study within the realm of science is not a novel or groundbreaking concept. The idea that industrial designers are integral to this interdisciplinary approach to the science of materials, is.

All the scientific disciplines we are aware of today stem from an original parent discipline. Whether it is alchemy or physics, there is cross-pollination of knowledge all along the board. It is not a stretch to suggest interdisciplinary scientific research is beneficial to advance material processes and product design. Montgomery (1999) realizes this. He asserts scientists and engineers have a crucial role in these activities. Other research unveils the benefits of such interdisciplinary efforts in science. Fox and Rohlich (1967) view “interdisciplinary inquiry as essential for the solution of certain kinds of environmental problems” (Fox & Rohlich, 1967).

Biomimetics

The field of biomimetics in essence is interdisciplinary. “The well-organized multifunctional structures and biogenic materials found in nature have attracted the interest of scientists working in many disciplines” (Rao, 2003, pp.660). Rao (2003) defines biomimetics as a “field of scientific endeavor, which attempts to design systems and synthesize materials through biomimmicry” (Rao, 2003, pp.659). Bio means life and mimesis means imitation. Fish (2009) defines biomimetics as an approach that seeks to incorporate design research from living organisms into engineered technology by mimicking organic processes.

Prior research strongly supports the idea that biomimetics--which includes but is not limited to chemistry, biochemistry, geologists, physics, biology, material engineers, material scientists, and environmental scientists--holds strong potential in dealing with complex environmental and economic issues. For example, Rao (2003) explains that “material scientists view biomimetics as a tool for learning to synthesize materials under ambient conditions and with least pollution to the environment” (Rao, 2003). Geologists are interested in the biomineralizaton of biomimetics. Biochemists are interested in biomimetics because of the interaction of biopolymers with ions of metals, which leads to mineralization in living organisms (Rao, 2003). This paper is thus concerned with advanced technologies derived from scientific discovery within the scope of Biomimetics. The study of biomimetics offers the greatest potential in the creation of materials and technologies that are benign to our environment.

In the first half of the 20th century researchers found insights into complex physical and chemical phenomena. This led to the current day understanding of nanoparticles and marcroparticles which are termed synonymously with colloids and polymers respectively (Fish, 2009). These are the building blocks for miniature stable tissues. There are also multicellular and single-celled organisms have the ability to produce structure tissues like bone, teeth, shells, skeletal units, and spicules (Sarikaya, 1999, as cited in Lowenstam, 1981). “Natural materials are mostly constituted from organic, inorganic crystals” (Rao, 2003). These crystals give rise to materials that can be used practically to produce products that fulfill human needs without extracting finite resources from Earth.

The following are advanced technological processes that have similar capabilities. Synthetic biology can construct biological systems through manipulation of genomes to construct novel biological systems (Fish, 2009). Bionanotechnology can create materials via peptide-based production (Rao, 2003). Reticular synthesis is the construction of crystalline solid-state materials from molecular building blocks (Yaghi, O’keefe, Ockwig, Chae, Eddaudi & Kim, 2003). It is this synthesis of materials via manipulation of biological means that holds the potential solution to solving the issues relevant to present day production processes. Although these technologies are not without their controversies, they suggest production means that do not have harmful effluents. They are compatible with the ecosystem. Yaghi et al. (2003) claims that the synthesis of new materials is recognized as a crucial stepping-stone in the advancement of technology.

The main idea behind the science is to create inorganic particles that can ultimately produce technologically stable materials for creation of solid-state products. Yaghi et al. (2003) confirms to date these materials have been used for medical products and electronics. There is potential to create other materials that can branch apart from these products into other industries. These materials include silk, ceramics, and other materials with elastic fibers (Rao, 2003).

Possibly the most interesting work in the field today is that of Neri Oxman and her founded Materialecology. Being an architect--MIT Phd Candidate--a medical scholar and computer engineer, she is internally interdisciplinary. Her work spans many disciplines in which biomimetics is at the heart of her innovation.

> Materialecology was formed in 2006 by Neri Oxman as an interdisciplinary research initiative that undertakes design research in the intersection between architecture, engineering, computation, and ecology. As such, this initiative is concerned with material organization and performance across all scales of design thought and practice. As such, it seeks to promote and define a design research agenda which is ecological in nature, in ideology and in material practice; it aims at embracing the evolving elements of change in both social constructs and environmental descriptions of the ever changing built environment. Materialecology undertakes research in advanced digital applications for architectural practice and pursuits using their contribution to design a paradigm promoting generative design processes (Oxman, 2006).

Oxman's efforts exemplify the design leadership needed in this vastly complex world of products and resources. These types of interdisciplinary examples are becoming more popular as we move into the murky future. As suggested by this paper, there will be adversity to overcome. But this adversity is far outweighed by the benefits of such collaborative and advanced approaches.

Discussion

Collaborative effort into scientific knowledge creation has been a continual process that parallels the evolution of man. It is evident that these efforts are integral to moving forward into the future of product design. Interdisciplinary approaches vary depending on the complexity of the project. When it comes to environment and economy which balances an inexhaustible amount of needs and vested interests, the complexity of the issue is unimaginable. This means a coherent body of knowledge detailing how best disparate disciplines should work together is paramount to future design and engineering efforts. Benefits to interdisciplinary design efforts are numerous. The most important benefits being that of speed and an ability to deal with complexity. Strength in numbers is also a benefit. Members' strengths supplant for others' weaknesses. The positive contributions of a team are evident. Goal orientation and group motivation become catalysts for innovation and creativity. Though there are benefits to interdisciplinary design teams, there are also hurdles to be reckoned with. Failure of communication mechanisms is a major hinderance. Lack of unified understanding also vitiates interdisciplinary team efforts. Murky organizational goals do not help the process. If resources are scarce, roles and responsibilities are compromised. There can be a loss of information when it transfers down and upstream. This goes back to the failure of communication mechanisms mentioned above (Safoutin & Thurston, 1993).

Currently the practice of interdisciplinary approaches exceeds the research. Vernacular is difficult to pin down. Theories become unclear. These impediments give rise to a necessary set of critical factors which are relevant dependent on the complexity and details of any given project. Holland et al. (2000) and Frankel and Tsuji (2005) give us examples of these important factors. These include high quality of leadership, mutual respect between members, group accountability, flexibility, humor, and organic but structured organization. Insensitivity to constructive criticism and emotional intelligence among members is important. These factors increase the chance of a successful interdisciplinary team project.

There are several different advanced technologies that have the potential to produce the outcomes that product design needs to fulfill environmental and economical issues that are the concern of this paper. Whether through synthesis of polymers or inorganic materials, the fact that they have the ability to be manufactured biologically is what makes these technologies so promising. This is currently being applied and there is hope for more widespread use within industrial design.

Biomimetics is a long standing scientific field that is interdisciplinary in its nature. Disparate disciplines are interested in its potential for varying reasons. Geologists are curious about biomineralization; while chemists keep tinkering with the genome. On any scale there is vast potential in figuring out and altering biochemicals and processes to create engineered technology.

Proposal/Conclusion

As technologies advance in biomimetics and material synthesis science, industrial designers must become more involved in the process. Industrial designers must look forward to the future and as Wayne Gretzky did (he is considered the greatest professional hockey player ever to play); he went to where the puck was going, not where it was. Scientists will no doubt move forward with technological advancement. It will be up to designers and other entrepreneurial types to envision the future uses of synthesized materials. A framework for an interdisciplinary approach should be created now for the time when these processes are introduced into the mass market. The beginning of such a framework is suggested in Figure 1 on the following page. The four circular domains represent different specialized knowledge. The volume of those domains correlates positively with the amount of information that flows within. Two-way arrows suggest the controlled free flow of information. Disciplines must be communicating within their domains, suggested here, for this model to be successful. The industrial designer's role within this model is, as suggested before, part communicator and part visionary. To do this effectively the industrial designer must be a generalist of sorts. They must posses information from all domains including the critical terminology and cultural awareness of each. This would allow the industrial designer to move in and out of these domains offering and borrowing information for application towards their product vision. If this job of "creative messenger" is done effectively, there would be unmatched synthesis of original ideas that will foster the creation of breakthrough products and processes for many industries.

As mentioned, the industrial designer within this model must be a generalist to do so. This would require a deep understanding of economic principles, advanced scientific theory and of course the artistic and engineering skills that are currently required for the present day industrial designer. This leaves a bevy of educational pathways to be pondered. Suffice it to say, the future industrial designer would benefit from having more than a B.I.D.

This framework is already in flux because relevant disciplines are part of a technological and design oriented continuum that is not separate from the historical and sociocultural fabric. Designers, scientists, and engineers must realize that in the the last half century this continuum has increased in speed to a dramatic degree. Realizing this will allow them to assert control over product, technology, and science, doing so in an interdisciplinary fashion. It is the interdisciplinary nature of these sciences that has moved technology to this point. It is also the interdisciplinary nature of science and its collaborative knowledge creation through which the field will progress. Designers will have to play an integral role in understanding new knowledge of materials, its capabilities and application. They will also need to be savvy communication facilitators, using general knowledge of many different disciplines to foster synergy between those disparate fields of study. It is an exciting but also a dire time wherein innovation and interdisciplinary efforts are pertinent to our future standard of living on Earth.

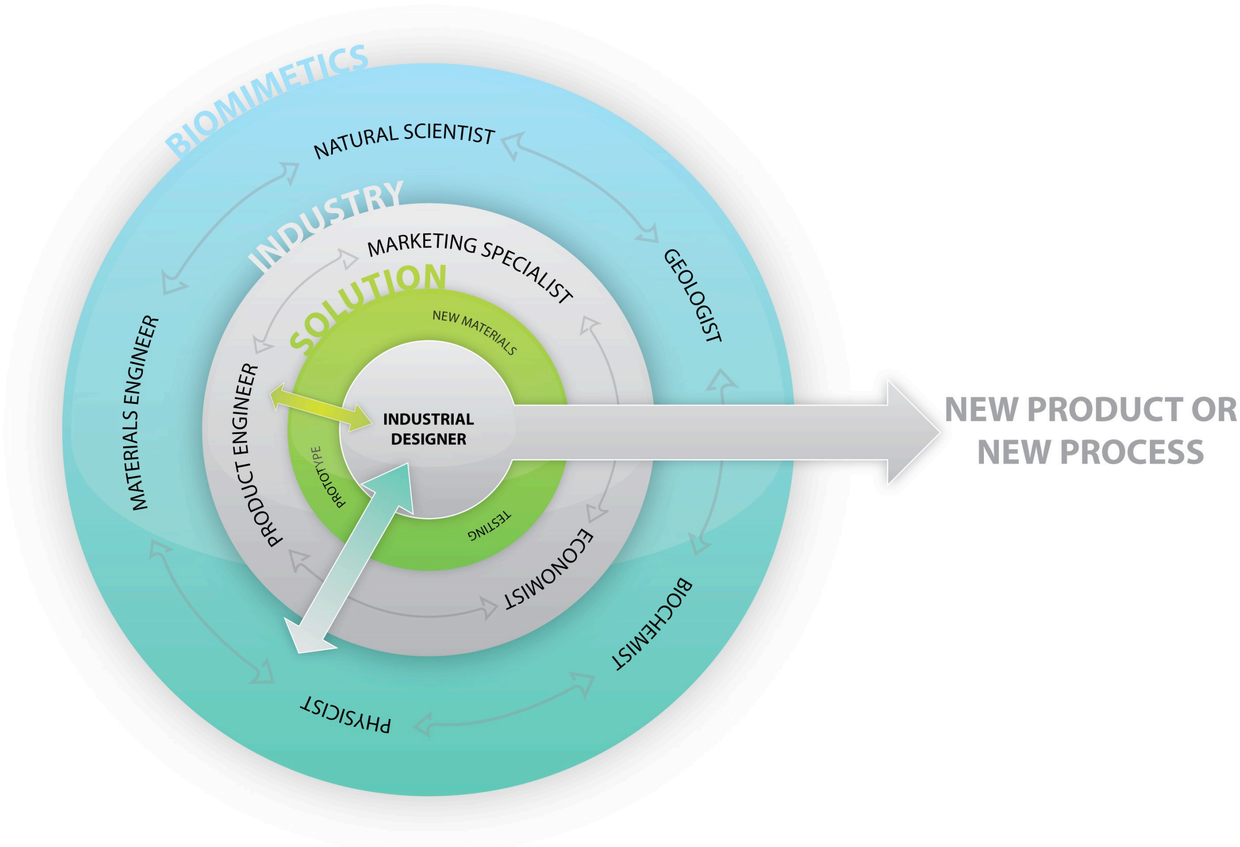

Fig 1. Suggested Interdisciplinary Design Team Structure

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