

Design and Interdisciplinarity: the improbable introduction of “fundamental physics” in a design school

Annie Gentes^a, Anne-Lyse Renon^{b*} and Julien Bobroff^c

^acodesign lab, Telecom Paristech

^bENSCI-Les Ateliers

^cUniversité Paris-Saclay

*annelyse.renon@gmail.com

DOI: 10.21606/drs.2016.357

Abstract: This paper analyzes the introduction of fundamental physics in design education as a pedagogical method that brings interdisciplinarity into play. It presents the framework of three workshops that took place in a design school. For each workshop, a theme was chosen by the designers and the professor of physics: superconductivity in 2011, quantum physics in 2013 and light and optics in 2014. The authors suggest that introducing physics in a design curriculum was thought in terms of an “a fortiori” education program that would help practitioners to draw pertinent questions and responses whatever the situation. The authors suggest therefore that the curriculum had five goals that correspond to a model of design: affective (how to cope with uncertainty), reflexive learning (how to cope with processes rather than contents), cognitive (how to cope with non knowledge), economic (how to cope with the industrial society of innovation), and political (how to cope with the equality of disciplines and “indiscipline”).

Keywords: Design Education; Interdisciplinarity; Expansive Learning; Design Theory

1. Introduction

Design education is organized so as to teach students how to be creative (Cross, Christiaans, and Dorst, 1994; Folkmann, 2010; van Dooren, Boshuizen, van Merriënboer, Asselbergs, and van Dorst, 2013; Lu, 2015; Tovey, 2015), have a theoretical and visual culture (Brookes, 1992; Dutton, 1991; Gall, 2008; Chin, 2011; Hadjiyanni, 2014), solve problems with methodological and analytical techniques (Schon & Wiggins, 1992; Goldschmidt & Smolkov 2006; Adams, turns, and Atman, 2003; Ozkan & Dogan, 2013; Daalhuizen, 2014), to create industrial and social value, community of practice (Lave and Wenger, 1991, Wenger, 1998),



This work is licensed under a [Creative Commons Attribution-Non Commercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/).

and multi-dimensional treatment (Engeström, 1987). One of the issues of the design curricula is to help creative skills intersect with theoretical knowledge (Gentes et alii, 2015). Some programs actually engage the students into scientific literacy with the usual argumentation as reported by Fenster (2010): sciences are helpful even for students who do not intend to engage into a scientific career because they are part of a general education (Donnelly, 2006). Sciences are therefore part of a cultural heritage considered the literacy of contemporary humanists. Science literacy is also supposed to help people make better reasoning and therefore helps them better manage their lives. As far as design education is concerned, Findeli (2001) points out that design has been considered as an applied science. However he remarks the impossibility of listing the infinite number of sciences that could be applied by design. Yet design also builds a relation to other sciences. The question is whether the interdisciplinarity is conceptual (search for meaning) or instrumental (functional aim) or, as we make the hypothesis, “expansive”. By expansive, we mean “constructing and implementing a radically new, wider and more complex object and concept for their activity” (Engeström and Sannino, 2010). From this point of view, what would it be to think about design education, not only in a *designerly way of knowing* (Cross, 2001), but to evaluate different modalities of expansive learning” (Engeström, 2001).

How do students learn how to handle interdisciplinarity in action, through workshops, documents, and artifacts? How do they manage not only the knowledge but also the non-knowledge (Mathieu and Schmidt, 2014) that goes with collaborating with other disciplines? How does this interdisciplinary framework support an expansive learning rather than an accumulative one? The underlying question is what kind of learning is targeted by educational frameworks that bring together design and sciences.

To answer these questions, we will describe a design education program organized by a professor in fundamental physics, Julien Bobroff with students of a school of design, ENSCI-Les Ateliers, in Paris, during several thematic workshops called “Form and Material”, supervised by two designers and educators, François Azambourg and Clémentine Chambon. In the discussion, we present the five properties of the framework of this program that we derive primarily from interviews of the actors who organized this program, and from observations of opening and closing sessions. The five properties are: affective, cognitive, reflexive learning, economics, and political. These properties presuppose a model of design and design education. Finally we will propose a conclusion about this *a fortiori* strategy in design education and how it relies on expansive learning.

2. Interdisciplinarity in design education

Multiple interdisciplinarity exist as Huutoniemi et alii (2009) who analyze their typology and indicators, stress. In education, the definitions also vary from the lowest degree of integration to reinventing and refiguring the fields of knowledge (Klein, 2006): Lenoir, Geoffroy, and Hasni identified 8 distinct forms of interdisciplinarity (Lenoir and alii, 2001).

Alain Findeli, a historian of design education, studied in a seminal article (Findeli, 2001) how

the management of disciplines and “proactive” attitude in several historical schools of design (such as Ulms or Chicago), relied on a balance between art, sciences, and technologies with various emphases on either one or another. Ezio Manzini (2009) also observed that contemporary design schools could be considered as “agents of (sustainable) change”. In his analysis, design educational programs play a fundamental role in “new scenarios for the future”, and the new challenge regarding design education is not so much to accumulate research and knowledge about everything but to know how to manage the “values of design research”. One of the consequences of what he calls “new design knowledge” is that all current disciplines can come into play to support a designing activity. This issue of managing interdisciplinarity is tackled in specific ways in professional settings (Jacobs, 1989; Luecht and alii, 1989; Austin and alii, 2001). For Manzini, co-design and the collaboration of large teams makes it possible to achieve complex projects. But for students, it is a daunting perspective.... In this article, we are interested in understanding how a design school can train its students towards this interdisciplinary co-design, or how to engage in a dialog with disciplines. As pointed out by Wooyoung Sung et al. (2015), most of industrial design education is based on the “studio-based design pedagogy”. The format is perfectly adapted to situations where the problem is relatively well identified. But when faced with complexity, “industrial design educators may need to consider an approach that is more interdisciplinary and that seeks solutions beyond those found in one design domain or other”. Interdisciplinarity in this educational context goes hand in hand with the increasing scope of design projects and the wider range of design productions.

By studying a case of education where the disciplines that at first sight have nothing in common, are brought together, we want to better understand how design uses interdisciplinarity in a designerly way to produce new objects (Gentes, 2015, Tovey, 2015). Our hypothesis is that interdisciplinarity in design can be better understood if we look at the characteristics and properties of these interdisciplinary situations to understand how they can actively support invention.

3. Field work : interdisciplinarity in practice

3.1 Context: an unlikely encounter between design and fundamental physics

The analysis of the literature on design shows numerous collaborative programs between Science and Design (Cross, 1993, 2001; Bruffee, 1999; Stahl, 2006; Renon, 2015). While interdisciplinarity is advocated by educational institutions and sustained by the analysis of professional design practices, many students who are introduced to design multidisciplinarity are afraid of the vast array of disciplines that they should know and use. The question is how to train for an almost infinite set of knowledge? Is it even possible to do so or is it a myth? And how are students prepared to raise up to the challenge of not understanding the depth of other disciplines that they must work with?

To address these questions, we chose to study a series of collaborations, engaged since 2011, between a professor in fundamental physics and designers in a design school.

Investigation of fundamental physics problems by design is not entirely new (Kelly, 1959; Chi and Glaser, 1979; Chi and alii, 1981; Chi and alii, 1989). However it is still an institutional exploratory space for design education. We chose this experiment first because it is a test bed for pedagogical explorations of the relations between science and design. We also chose it because one of the authors (JB) could participate in the different stages of the project, from its definition to its implementation allowing for a longitudinal approach.

3.2 Description of the experiment: “fundamental physics and design”

The experiment that we describe was not planned as such, as the director of the school at that time recognizes. According to him, design schools have more “natural partnerships” with engineering sciences. The interviews with the different actors of the projects confirms this exploratory dimension of the project. An encounter between fundamental physics and design can be surprising. As it was a first in the school, a number of methods were used to make sure that the students would be able to tackle the challenge. A first 5-days collaboration with the physics professor was undertaken to “test” the feasibility of this collaboration and to reassure the students and the different actors of the project. As this first small workshop was successful and as the students were enthusiastic, the direction of the school and the faculty decided to do another, longer, 4 months workshop the following semester. The scientific director of the school then decided to learn from this experience and started a research program to analyze the interactions and productions of these peculiar workshops. All the subsequent workshops followed the same format.

The « fundamental physics and design » workshops gather each time about fifteen to twenty design students of mixed backgrounds and levels but with no specific qualification in science. They are supervised by two professional designers, François Azambourg and Clémentine Chambon, and a physicist, Julien Bobroff. For each workshop, a physics theme is chosen by the designers and the physicist together among the areas of expertise of the physicist : superconductivity in 2011, quantum physics in 2013 and light and optics in 2014. Focus is put on fundamental topics and not so much on technologies or applications. For example, the quantum physics project focuses on basic quantum phenomena such as wave-particle duality or tunneling effect. The light project focuses on the electromagnetic and quantum nature of light, not on technologies of lightings. During the workshops, students are first given outreach seminars by the physicist together with physics lab visits and open discussions about the physics at play. The students are then asked to conceive a design project inspired by the scientific material during a four months period with two days per week devoted to the workshop.

The students’ projects can address a pedagogical goal and serve for outreach purpose, for example videos displaying physics phenomena, or devices demonstrating physics experiments. But the projects can also end up in artefacts inspired by science but with no educational purpose, for example lightings, clothes, or jewels. Students are encouraged to experiment various formats and domains. These workshops explore a wide variety of subjects (physics education, but also security, games, food, household use, sound, art,

sport...), thanks to the help of the teachers-designers who make sure that every student explores a different path. The resulting projects are then shown to the rest of the school in a collective presentation and exhibition. They are also displayed in videos gathered in a website (ref : www.supraconductivite.fr www.designquantique.fr www.lightsciencedesign.fr) and further used in various outreach activities : exhibits in science museums, outreach talks, science fairs... A detailed description of the artefacts produced by the students can be found in Bobroff et al. (2014) for superconductivity and in Jutant and Bobroff (2015) for quantum physics.

3.3 Research methods

One of the workshops has already been described and analyzed through a participative observation and a semio-pragmatic analysis of the documents and artifacts produced by the students by Jutant et Bobroff (2015). Elaborating on Jutant and Bobroff, who pointed out the diversity of popularization strategies deployed by the students, we wanted to analyze the framework of these activities that give the ideological background, the legitimization of the production, the specific “episteme”, that is the presuppositions that found the practice and a priori knowledge of this experience (“that defines the conditions of possibility of all knowledge, whether expressed in a theory or silently invested in a practice”, Foucault, 1966, 168). We therefore did qualitative interviews with the actors post workshops with a focus on how the proposition of the workshops had been framed (Becker & Geer, 1957; Tedlock, 1991). We also did an observation of the opening and closing sessions when the main goals are being presented.

4. Analysis

4.1 First results

The analysis of the interviews shows that the actors make hypothesis on the specific difficulties and key factors of success of the whole operation. The designers and the physicist explain that one of the main difficulties for the students is to deal with abstraction:

“ - We wanted to reassure the students on the objects they would have to produce, and by this way remove inhibitions they may have with the scientific knowledge they are not supposed to *have*.”

One of the supervising designers said that she was disconcerted by the choice of quantum physics in particular, because, as she says:

“ - It was very abstract and made it difficult for the students to project themselves in objects”.

The framework is then described as a passage from the abstract to the concrete.

1. First, the physicist is present all along the workshop and from the very beginning of the program, during the presentation of the different workshops to the students, since the physicist and the designers describe the “physics and design” workshop together. Then the

physicist attends the workshop about two to three times per month. According, to him and the supervising designers, it allows a more trustful and open dialog with the students. After a few weeks, they do not hesitate to ask questions about what they do not understand:

“It seems that my presence has a comforting effect: the fact that I’m enthusiastic about their productions and accessible on the science side seems to reassure and motivate the students.”

The presence of the physics teacher is very important as the authority figure of scientific opinion (Polanyi, 1962). The students want to do their best to show him their productions. So each time he comes, designers supervisors have observed moments of acceleration of production, and new exploration and consolidation periods. The designers emphasize that the “enthusiastic” and dedicated presence of the physics professor was extremely important in reassuring the students. Even the director of the school had individual discussions to support the project with the students.

2. The students have the freedom to explore the subject with any medium they choose, as they are supposed to take a posture of designer. It is not a question of truth or error but how to acquire a position towards a body of knowledge. To counterbalance the abstract dimension of the project, the students were invited to visit the physics lab “to anchor the workshop in tangible places of scientific practice.” Another method was to resort to usual and well known design methods. As one of the designers pointed out:

“ - We asked the students to use a method they know well, the scenarios of use, so that the project appeared “same as usual”.

Two levels of production qualify the relation between scientific knowledge and design: either “inspirational” or more advanced. As the physicist says:

“ - I also insist that I don’t expect them to understand every aspects of the physics at play: they can be “superficial” in their understanding. Also I make it clear that I will be there often and available to discuss and provide explanations as much as needed.”

As he mentions, sometimes the students want to make “pedagogical” projects which explain physics:

“ - In this case only (not the most common), I’m more demanding on the science exposed in their projects, and I ask for a validation process where I’m allowed to correct the scientific part if needed.”

3. The productions are used in scientific communication contexts such as conferences, exhibitions, science museums such as Cité des Sciences in Paris (<http://hebergement.u-psud.fr/supraconductivite/>), and the thematic of the workshops usually fit with major scientific events. The work done will therefore be validated outside of the workshop. For example, a student conceived a wooden artefact to mimic some mathematical representations of wave functions. This artefact originally designed for a specific use in an outreach context in science museums happened to be used later in education as an introductory tool to help physics students think about the concept of the wave function and, on the other side, in a design exhibit (Biennale de Saint-Etienne, France). This gives an

additional value to the students' productions. This validation is a guarantee that their work is meaningful in a scientific context. What kind of meaningfulness still needs to be addressed though.

4. The physical presence of all the actors during the workshop emphasizes the collaboration. Even before producing anything, the students can anticipate a certain form of complementarity. There is a dramaturgy of the collaboration as well as an effective contribution of all the participants. In addition, there is the staging of an equality of disciplines. Science is not above design (the physicists: "I guess this perhaps reassures the students that I'm reachable and enthusiast about this collaboration".) The claim of the experiment is that each body of knowledge (design and science), looks at the others' competence with "ignorant eyes" (Rancière, 1991). As the physicist says:

"I am not a designer, I will not teach the students how to do design. In the same way, they are not physicists, and I won't expect them to become so."

In other words, the actors insist that the identity of the participants is not changed by the experiment. Still a collaboration is presented as possible. The workshop is the way to materialize this collaboration in practice.

4.2 Discussion: the five properties of the "design and physics" workshop

From the interviews and the observations of the opening and closing sessions, we can describe the framing as such:

1. It has *affective* properties. The new workshop is considered as a destabilizing environment both by the supervising team and direction of the school. Indeed, the design students with no scientific background are faced with fundamental modern physics involving abstract concepts which may involve sophisticated mathematics or high-tech tools. Destabilization also occurs about the image of science itself, not embedded in applications or technologies, but from the point of view of fundamental research. However, the director shows and tells the students his confidence that designers can elaborate within such a difficult environment. He reaffirms his trust in the design students' capacity to grasp elements that are beyond their usual skills and knowledge. As we have seen in the previous section, the figures of power and knowledge also frame the affective challenge with legitimate authority. The underlying model of design is that it can be a psychological challenge that the supervising actors have to manage with dedicated care and attention and in particular trust and authority.

2. It has reflexive and an "expansive learning" (Engeström, 2001) properties: the emphasis cannot be on "contents" since there is little chance that the design students will be able to catch notions that require years of training in physics. They get some elements of contents through the course given by the physicist but they are mostly encouraged to gather their creative and making skills. There is therefore an abrupt shift from relying on learning something or learning how to make something, to using skills learnt in different classes and to put these skills into the project. The director is acutely aware that it is a particular

challenge because he observes that students have difficulties to put into practice something they have learnt in one class to another class or workshop. The framework is therefore not only centered on the capacity to reuse some competence learnt elsewhere, but also, because of its extreme qualities, it is a reflexive space on this particular practice since physics is not a class “proper”. The class is a test bed of designing through experience which is one of the design activity profiles analyzed by Cross (2001) and Cross and Kruger (2006). The students explore the background of their previous realizations and tap into all the knowledge they have so as to find similarities with the new design projects. It is also congruent with the model of the “reflective practitioner” described by Schön (1983, 1987).

3. It has a cognitive properties. Though the professor in physics tries to give as many vivid metaphors as he can - for example, he presents the quantum tunneling effect as if, when an object is projected onto a wall, a small tunnel opens up and lets the object go through; or he presents superconducting levitation as a giant invisible wave embedded in the material which swirls when a magnet approaches and repels the magnet - the students have to work past their non-knowledge to be able to produce an artifact or a representation. Some students even acknowledged the fact that *not* understanding the topic in-depth was a liberating factor in terms of creativity, as designers and physicist looks at the others’ competence with a priori “ignorant” eyes (to use Rancière’s expression in the “ignorant schoolmaster”). This is congruent with a theory of “projection” and transfer in design (Chow, 2009; Chow and Jonas, 2009). Designers bring together elements (whether facts, aesthetics features, concepts, methods) that apparently have nothing in common in a surprising way and create a new concept/ artefact. This unexpected encounter of seemingly unrelated elements is not only as in Peirce’s logics (Peirce, 1906) the way to find new hypotheses for facts. More importantly from a design perspective, it allows to create an unknown object. As the physicist says: “I’m here to discover new types of innovative and often unexpected points of view on my own scientific field, in terms of formats, representations, and understandings, which I can then reuse in various outreach contexts”. Based on Peirce’s definition of creative abduction (Roozenburg, 1993), we can consider that conception happens dynamically with concepts that are neither true nor false. These concepts or projects of artefacts, force the participants to look for solutions or knowledge that could bridge the gap between the fields that are brought together.

4. It has economics properties. Even if the body of knowledge is not expected to change with the experiment, students work with the uncertainty of the possible applications of scientific knowledge, and more broadly speaking with the uncertainties of the identity of objects. This seems to be an adaptation to the general mode of uncertainty that affects contemporary economics under the rule of radical innovation and that was pointed out by researchers in design (Morello, 2000) as well as in management and organization sciences (Le Masson, Weil, Hatchuel, 2006). Contemporary objects have no stabilized identity and designers cannot count on traditions of use for their objects. The director is quite clear about this: “nothing is going to be the same in twenty or thirty years from now. I want to make sure that designers will have the skills to adjust to an ever changing environment”.

Again the shift from knowing something and knowing how to make something to knowing a posture of continuous adjustment to a changing set of environmental data is at the core of the framework. This kind of collaboration is the way to materialize this “changing environment” in practice.

5. It has political properties. The workshop organizes a form of emancipation (Rancière, 1991, 2009) from academic disciplines. First, the disciplines are represented by the professors participating in the workshops. As we have seen in the first results, the participants reinforce a sense of disciplinary identity by repeating that they will not change or become a hybrid between design and science. But at the same time, they offer a representation of the relations between disciplines that frees the participant of a strict and closed definition of disciplines. First, contrary to what often happens in the field of sciences, there is no hierarchy between disciplines. As suggested in the previous section of this article, the workshops stage and put into practice an equal collaboration. Second, since it is assumed that they will not become physicists, students are allowed to disregard the usual path to learning physics. This is made possible by a clear initial agreement with the scientific partner that the produced artefacts do not need to be necessarily scientifically accurate. There is still a relation to science. The workshop is like a shortcut that privileges borrowing facts, theories, images, from a discipline, rather than using a structured disciplinary body of knowledge. This seems to be the case for all the actors that agree to play out of their leagues since the physicist is no designer, the designer is no physicist and there is a general agreement that there are other ways of building knowledge than accumulating it.

5. Conclusion: design and science in education: a framework for expansive learning

What is the role of science in framing the design workshop? Contrary to what could be expected, the physicist is not there to fill up the gaps of knowledge in physics. While the interviews show that some students are more literate in physics at the end than at the beginning, the purpose of the curriculum is not to turn them away from design in the direction of physics, in a movement from “incompetence” to “competence”. The introduction of physics in design education is not primarily for the sake of “contents”, nor is it entirely for the sake of physics. In these workshops, the interdisciplinarity of design does not rely on an illusion of universal knowledge either within one person or even a group. The interdisciplinarity is not thought in terms solely of the addition of knowledge bases, or people representing these different knowledge bases as observed in innovative companies. In the framework that we analyzed (it could be different in a different situation) interdisciplinarity does not appear to be conceptual in the sense of articulating two disciplinary fields together that would finally fit thanks to the emergence of new mutual concepts. The field of physics is not presented as being challenged by the field of design nor the field of design is impacted directly by the discipline of physics.

Finally, interdisciplinarity is not “instrumental” in the sense that physics as a science would need design to accomplish some of its goals, or design would use physics to pursue its tasks. To come back to our initial question whether the interdisciplinarity displayed in these workshops is conceptual (search for meaning) or instrumental (functional aim), we can therefore say that it is neither. But something is nonetheless accomplished through the introduction of fundamental physics in a design curriculum. By bringing a discipline without a priori overlap with design knowledge, the workshop is an exploration of what is fundamental about design practice and knowledge. The whole framework makes an a fortiori demonstration of what design and design learning is about.

As we have seen in the discussion, it makes a demonstration of the capacity of designers to cope with five major properties of a design situation: design can be a psychological challenge because it shows the limits of design knowledge not only on a personal level but because of the actual disparities between disciplines; it is a reflexive process where designers tap into their personal history and experience of other projects - in effect introducing even more facts in the project - to create new representations at the crossroads of disciplines; it is a cognitive challenge since it deals with non-knowledge in the projection towards an X (unknown object); it is an economic challenge since there is no stability of objects in a society of continuous innovation; finally it is a political claim about the relationships between disciplines that neglects their boundaries and hierarchy. The framework is designed so as to rehearse and cope with these difficulties. It points to a model of design and learning in design that involve expansive learning as defined by Engeström and Sannino (2010). By expansive, we mean “ constructing and implementing a radically new, wider and more complex object and concept for their activity” (Engeström and Sannino, 2010). First, the framework relies on the reasoning that who can do more can do less. Namely, if a student follows this type of workshops, he will “a fortiori” be able to participate in any other interdisciplinary project, especially those that involve science. The five different properties of the workshop are probably more or less present in the other workshops but the latter pushes their logic beyond the ordinary. If one can learn how to design in such conditions one will be able to design in all circumstances. The response to the challenges of design situations as they are staged through the workshops is to promote expansive learning because it is learning about expansion: the tools, the frameworks, the personal and group dynamics, the way to learn... The design students are not supposed to learn something that they would not know yet, but to construct their own knowledge and imagine objects and practices, by their “non-knowledge”.

Interdisciplinarity in the workshops therefore plays a reflexive role on design practice. Understanding how the situation of learning is framed is therefore fundamental but is not enough to see how design in practice solves the tensions that such a strange encounter brings. As students are not asked to adopt reproductive gestures, but productive postures, our future research (similar workshops are programmed in the course of 2016 with the same protagonists) will evaluate how the students actually use their capacity of projection, transfer and hybridization, build artifacts, scenarios, and other students’ productions, as well

as the nature of the displays (in their “plastic artwork” properties), and the evaluation of the objects (in their diversities) to solve the interdisciplinary tensions.

Acknowledgements: This work benefited from the support of the ANR Descitech. We would like to thank Joel Chevrier, Mathias Béjean and Olivier Hirt for their support and collective discussions. We also want to thank Ensci - Les ateliers school, and most of all we would like to thank François Azambourg, Clémentine Chambon, Véronica Rodriguez, and all the students of the workshops.

6. References

- Austin, S., Steele, J., Macmillan, S., Kirby, P., & Spence, R. (2001). Mapping the conceptual design activity of interdisciplinary teams. *Design studies*, 22(3), 211-232.
- Becker, H., & Geer, B. (1957). Participant observation and interviewing: A comparison, *Human organization*, 16(3), 28-32.
- Becker, H. S. (1958). Problems of inference and proof in participant observation, *American sociological review*, 652-660.
- Chi, M. T., Feltovich, P. J., & Glaser, R. (1981), Categorization and representation of physics problems by experts and novices, *Cognitive science*, 5(2), 121-152.
- Chi, M. T. H., Glaser, R., The measurement of expertise: Analysis of the development of knowledge and skill as a basis for assessing achievement, in: E. L. Baker & E. L. Quellmalz (Eds.), in: *Design, analysis, and policy in testing and evaluation*, Beverly Hills, CA: Sage Publications, pp. 37-48.
- Bobroff J., Azambourg F., Chambon C., Rodriguez V. (2014), Design and Superconducting Levitation, *Leonardo*, Oct. 2014, Vol. 47, No. 5, MIT Press, pp. 474-479.
- Bremner, C., & Rodgers, P. (2013). Design Without Discipline. *Design Issues*, 29(3), 4-13.
- Bruffee, K. A. (1999). *Collaborative learning: Higher education, interdependence, and the authority of knowledge*. Johns Hopkins University Press, 2715 North Charles Street, Baltimore, MD 21218-4363.
- Chi, M. T. H., & Glaser, R. (1979, April). Encoding process characteristics of experts and novices in physics. In *Symposium on Process Models of Skilled and Less Skilled Behavior in Technical Domains*. American Educational Research Association.
- Chi, M. T., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive science*, 5(2), 121-152.
- Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive science*, 13(2), 145-182.
- Chow R., Jonas W., Schaeffer N., Piercean Abduction, Signes & Transfer. *8th European Academy Of Design Conference - 1st, 2nd& 3rd April 2009*, The Robert Gordon University, Aberdeen, Scotland EAD09/160.
- Cross, N. (1993). Science and design methodology: a review. *Research in engineering design*, 5(2), 63-69.
- Cross, Nigel, Designerly Ways of Knowing: Design Discipline Versus Design Science, *Design Issues*, 17 (2001), 49–55.
- Drew, L (2015) The Experience of Teaching a Creative Practice: An Exploration of Conceptions and Approaches to Teaching, Linking Variation and the Community of Practice, in Tovey, M. *Developments in Art and Design Education*, Gower.
- Engestrom, Y. (1987). Learning by expanding. *Helsinki: Orienta-Konsultit Oy*.

- Engeström, Y. (2001). Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of education and work*, 14(1), 133-156.
- Engeström, Y., & Sannino, A. (2010). Studies of expansive learning: Foundations, findings and future challenges. *Educational Research Review*, 5(1), 1-24.
- Findeli, A., 2001, « Rethinking Design Education for the 21st Century: Theoretical, Methodological, and Ethical Discussion », *Design Issues*, Volume 17, Number 1, Winter 2001, Massachusetts Institute of Technology.
- Foucault, M (2002) *The Order of Things. An Archaeology of the Human Sciences*, Routledge, cop. 1970 (1966).
- Gentes A., Valentin F., Brulé E. (2015) Mood boards as a tool for the “in-discipline” of design. *International Association of Societies of Design Research (IASDR 2015, Brisbane)*.
- Gentes A. (2015), Arts et sciences du design: la place des sciences humaines. *Sciences du Design*. 2015/1 (n°1), Presses Universitaires de France.
- Hatchuel, A., & Weil, B. (2003). A new approach of innovative Design: an introduction to CK theory. In *DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm*.
- Hatchuel, A., Weil B. (2009), *CK Theory: an advanced formulation, Research in Engineering Design*, Springer.
- Hatchuel, A., Le Masson, P., & Weil, B. (2006). 13 Building Innovation Capabilities: The Development of Design-Oriented Organizations. *Innovation, Science, and Institutional Change: A Research Handbook: A Research Handbook*, 294.
- Huutoniemi, K., Klein, J. T., Bruun, H., & Hukkinen, J. (2009). Analyzing interdisciplinarity: Typology and indicators. *Research Policy*, 39(1), 79-88.
- Jacobs, H. H. (1989). *Interdisciplinary curriculum: Design and implementation*. Association for Supervision and Curriculum Development, 1250 N. Pitt Street, Alexandria, VA 22314.
- Jutant, C., Bobroff, J (2015) Objets de médiation de la science, objets de design: le cas du projet Design Quantique, *Communication et langages* n°183. To be published.
- Jutant, C (2010), « « La zone Xtrême » et ses publics télévisés: situations de communication multiples et ajustements permanents », *Communication et langages*, 166.
- Kelly, W., C., (1959), « Some Educational Activities in Physics », *The American Mathematical Monthly*, Vol. 66, No. 4 (Apr., 1959), pp. 308-310, Mathematical Association of America. URL: <http://www.jstor.org/stable/2309647>
- Klein, Julie, A Platform for a Shared Discourse of Interdisciplinary Education, *Journal of Social Science Education* © JSSE 2006 Volume 5, Number 2, September 2006, pp 10-18
- Kruger C., Cross N. (2006), Solution Driven versus Problem Driven Design: Strategies and Outcomes, *Design Studies*, 27, 527-48 <<http://dx.doi.org/10.1016/j.destud.2006.01.001>>.
- Lenoir, Yves; Geoffroy, Yvon; Hasni, Abdelkrim. 2001. Entre Le <Trou Noir> Et La Dispersion évanescence – Quelle cohérence épistémologique pour L’interdisciplinarité? Un essai de classification des différentes conceptions de l’interdisciplinarité. In: Lenoir, Yves; Rey, Bernard; Fazenda, Ivani, eds. *Les Fondements de L’interdisciplinarité dans La Formation à L’Enseignement*. Sherbrooke, 85-110.
- Luecht, R. M., Madsen, M. K., Taugher, M. P., & Petterson, B. J. (1989). Assessing professional perceptions: design and validation of an Interdisciplinary Education Perception Scale. *Journal of Allied Health*, 19(2), 181-191.
- Manzini, E. (2009). New design knowledge. *Design studies*, 30(1), 4-12.

- Mathieu N. & Schmid A-F. (Ed.), *Modélisation et interdisciplinarité*, Coll. Indisciplines, Quae, Paris, 2014.
- Morello, A. (2000). Design predicts the future when it anticipates experience. *Design Issues*, 16(3), 35-44.
- Peirce, Charles S. (1906). Prolegomena to an Apology for Pragmaticism. *The Monist* 16 (4):492-546.
- Polanyi, M. (1969) The republic of Science: Its Political and Economic Theory (1962), in: *Knowing and Being. Essays by Michael Polanyi*, Marjorie Grene (Ed.), University of Chicago Press, pp.49-73.
- Rancière, J. (1991). The ignorant schoolmaster: Five lessons in intellectual emancipation. Trans. Kristin Ross, Stanford University Press.
- Rancière J (2009), *The Emancipated Spectator* (2008).
- Renon A.L. (2015). Graphic design and Objectivity: Looking at Meta-Atlases, in: *Seeing Architecture. Design contribution to Knowledge Building*, Lantenois A. & Roufineau G. (Ed.) B42.
- Roozenburg, N. F. (1993). On the pattern of reasoning in innovative design. *Design Studies*, 14(1), 4-18.
- Schön, D. A. (1983). *The reflective practitioner: How professionals think in action* (Vol. 5126). Basic books.
- Schön, D. A., *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions*. Josey-Bass Publishers.
- Sfard, A. (1998). On two metaphors of learning and the dangers of choosing just one. *Educational Researcher*, 27(2), 4–13.
- Tedlock, B. (1991). From participant observation to the observation of participation: The emergence of narrative ethnography. *Journal of anthropological research*, 69-94.
- Tovey, M (2015). Designerly Thinking and Creativity, in: *Design Pedagogy*, in: Tovey, M. *Developments in Art and Design Education*, Gower.

About the Authors:

Annie Gentes is a researcher in Information and Communication Sciences and Head of the Codesign Lab. Her research focuses on contemporary practices of design in scientific research, political contexts, as well as the industry. She also works on the epistemology of design.

Anne-Lyse Renon is design researcher and PhD Candidate in Anthropology in Ecole des Hautes Etudes en Sciences Sociales (EHESS) in Paris. Her research focuses on Design and Aesthetic in Scientific Practices. She is research associate in the Design School ENSCI-Les Ateliers.

Julien Bobroff is a physics professor at Universite Paris-Sud. He conducts a research team "La Physique Autrement" (Physics Reimagined) devoted to interdisciplinary approaches to outreach research and innovations and to physics education.