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How to frame the un-known?

The odd alliance of design and "fundamental physics" in a design school

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Abstract

This paper analyzes the introduction of fundamental physics in design education as a pedagogical method that trains designers to create with the un-known. It studies how three workshops offered design students to work on: superconductivity in 2011, quantum physics in 2013 and light and optics in 2014. The authors observe that introducing physics in a design curriculum was thought in terms of an "a fortiori" education program that would help practitioners to come up with pertinent questions and responses even if they cannot comprehend all aspects of the problem. The authors looked at how the workshops were handled and suggest that the educational framework 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; Knowledge

Interdisciplinarity in design education

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), build 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), 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, Tovey, 2015). Some programs actually engage the students into scientific literacy with the usual argumentation as reported by Fenstein (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). Science literacy is also supposed to help people make better reasoning and therefore helps them better manage their lives. In fact, multiple interdisciplinarities 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). As far as design education is concerned, Findeli (2001) points out that schools of design (such as Ulms or Chicago) relied on a balance between art, sciences, and technologies and taught various disciplines that were judged necessary, in particular because design was considered as an applied science. However, he remarks the impossibility of listing the infinite number of sciences that could be applied by design. 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 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.

In our opinion, 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, the goal would not be so much about teaching *designerly way of knowing* (Cross, 2001), but to provide with different modalities supporting "expansive learning" (Engeström, 2001).

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. How do students learn how to handle interdisciplinarity in action, through workshops, documents, and artifacts? To answer these questions, we describe 3 design workshops called "Form and Material", organized and supervised by a professor in fundamental physics (Z), and two designers (X) and (Y). In the analysis, we focus on how the different actors frame the workshops: explain it to students, organize the interactions, pace the design work. 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 a cumulative one?

Based on the observations and interviews, we present five properties of this framework: 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.

Field work: interdisciplinarity in practice

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 interdisciplinarity 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 who is also one of the authors of this paper 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; Chii 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.

The opening of workshops “Form and Material” to fundamental physics

The “Form and Material” 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 (X) and (Y) and a physicist (Z). 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 visits to the physics lab 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-month period with two days per week devoted to the workshop.

There is a certain latitude in the definition of what the students’ projects are going to be useful for. Their project 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.

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).

Analysis of the “odd alliance”

The experiment that we describe was not planned as such, as the director of the school at that time points out. The “natural partnerships” of the design school are more 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 occurrence 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-day 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 step was successful and the students were enthusiastic, the direction of the school and the faculty decided to do another, longer, 4 month workshop the following semester of the same year. All the subsequent workshops followed the same format which include elements of speech (such as the goals of the students productions), and pedagogical organization.

1. 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.

2. The physicist is present all along the workshop. It starts during the presentation of the different workshops to the students, since the physicist and the designers present 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 don’t hesitate to ask questions:

   > “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.”

   In any case, the presence of the physics teacher is very important. When he is present at the workshop, the students want to do their best to show him their productions. So, each time he comes, we observed moments of acceleration of production, and new exploration and consolidation periods.

3. 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. To encourage students in exploration, the physicist qualifies different levels of integration between their activity and scientific knowledge. 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.”

The productions can and will be used in scientific communication contexts such as exhibitions, websites, science museums … The work done is therefore validated outside of the workshop. This gives an additional value to the students’ productions. This validation is a guarantee that their work is meaningful in a scientific context.

5. According to the actors, the framework also manages a passage of the abstract to the concrete. 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”.

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”. 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*.”

Discussion: the five properties of the “design and physics” experiment

From the interviews and the observations, the framework appears to have several properties that build a specific dispositive made of language, organization, places, interactions, that structure the distribution of power between the actors and the disciplines (Foucault, 1975).

1. It is an *affective* dispositive. The new workshop is considered as a destabilizing environment. 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 his confidence that designers can elaborate within such a difficult environment. For him, trust in the design students’ capacity to grasp elements that are beyond their usual skills and knowledge is at the core of this operation. As we have seen in the previous section, the charismatic (“enthusiastic”) presence of the physics professor is a part of the affective dispositive as well as the reassuring collective or individual discussions. 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 has to be managed with care and attention.

2. It is a *reflexive* and an *“expansive learning”* (Engeström, 2001) dispositive: 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 dispositive 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). Designers explore their own past and tap into their previous realizations so as to find similarities with the new design projects. During the workshop, the students have to do the same and actually think

about this way of doing design. It is also congruent with the model of the "reflective practitioner" described by Schön (1983, 1987) that is a rationale that is based on doing and stepping back.

3. It is a cognitive dispositive (Rusbult, 1997). 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 Pierce'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 is an economics dispositive. 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. 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). 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". 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 dispositive. This kind of collaboration is the way to materialize this "changing environment" in practice.

5. It is a political scientific dispositive. 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. The professors 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 happens most of the times between 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.

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

Studying these experiments, we had multiple goals:

- Beyond the particularism of these examples, what are the properties of these experiences and can they be replicated in different institutions?
- What kind of learning is targeted by educational frameworks that bring together design and sciences?
- How do these experiments teach us something about design as conception?

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, 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 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 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 wouldn’t know yet, but to construct their own knowledge and imagine objects and practices, by their “non-knowledge”.

The introduction of physics in the workshops therefore played a reflexive role on design practice, not because design knowledge must include more and more disciplines but because it can deal with all the principle challenges of any design situation.

In our research, understanding how the situation of learning was framed was 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.

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