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Human-Centred Research & Design for Inclusive Mobility. Section C-Doing Science

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Human-Centred Research & Design for Inclusive Mobility Section C – Doing Science



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Introduction

This document is a sequel to the working paper titled “*Human-Centred Research & Design for Inclusive Mobility. Sections A & B*” and published at HAL Science¹, the French open-access repository.

The whole work consists of five sections. Section A presents the French establishment Université Polytechnique Hauts-de-France (UPHF)² and the Laboratory of Industrial and Human Automation Control, Mechanical Engineering and Computer Science (LAMIH UMR CNRS 8201)³. The context of the work is described in terms of inclusive mobility, particularly regarding the human-centred design of technologies dedicated to human mobility and handicapped people. Section A also presents the technical and scientific equipment dedicated to mobility and transport at LAMIH.

Section B explains two human-centred theoretical approaches to design technologies and services dedicated to human mobility in the time of Industry 5.0. As a reminder, according to the European Union, the European industry will serve society better by complementing the techno-economic vision of Industry 4.0 (digitalization, AI technologies, efficiency and flexibility of production) with the Industry 5.0 perspective which focuses on human centricity, sustainability and resilience.

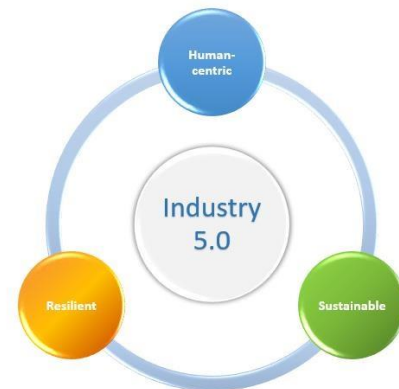


Figure 1 Industry 5.0 (Breque et al., 2021, p. 13)

Section C (the present document) is about science, more precisely the basics of research through explanatory definitions and three research approaches (quantitative approach, qualitative approach, and mixed methods approach). Indeed, the students who are interested in the human-centred design have to know the scientific methods used along the design process.

Section D will deal with ethical considerations in research and Section E with article writing.

¹ <https://hal.science/hal-03726812>

² <https://www.uphf.fr/en>

³ <https://www.uphf.fr/lamih/en>

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Human-Centred Research & Design for Inclusive Mobility. Section C—Doing Science

Section C deals with the aspects of research which can be useful to the students and future research candidates interested in the design of human-centred technologies and services, human-machine systems, and socio-cyber-physical systems. Some general concepts related to science and research are defined in the first chapter (§ C.1). Next, three kinds of research approaches of human and social sciences are described, namely, the quantitative, qualitative and mixed methods research approaches (§ C.2); indeed, these approaches are widely used along the design process of human-centred technologies, particularly in the phases of needs analysis, specifications, tests and evaluations (Figure 2). The conclusion is about the concept of validity.

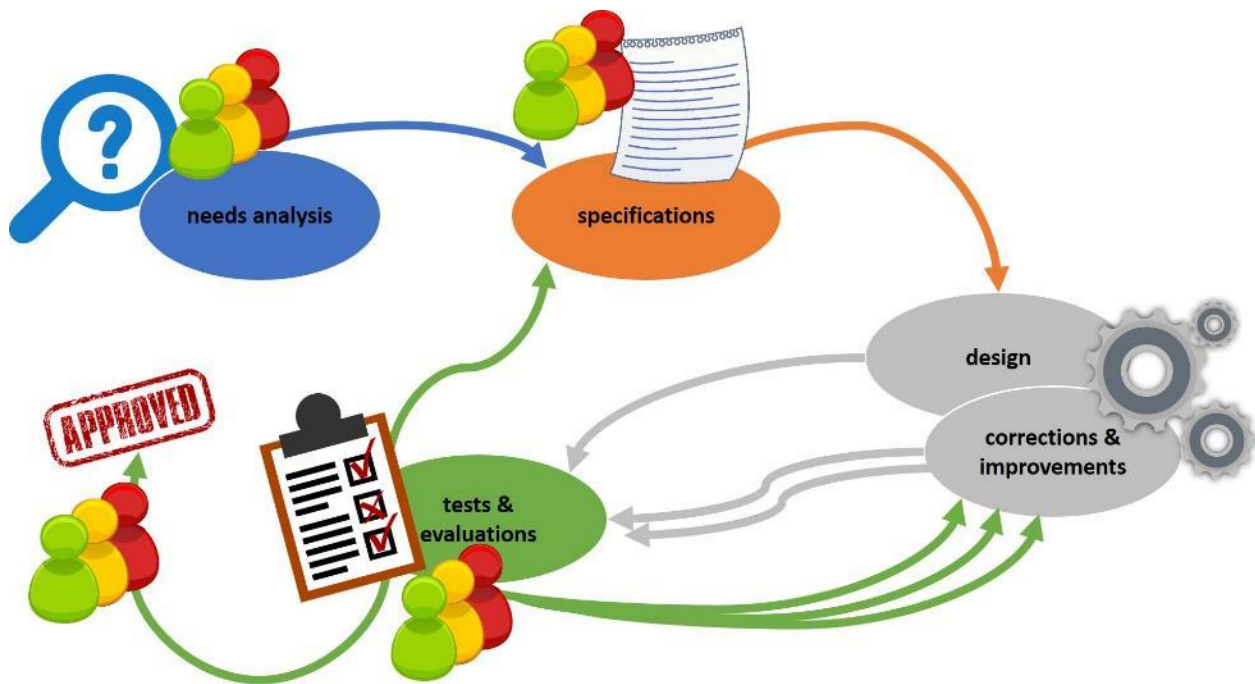


Figure 2 Human-centred design approach: the human (users, operators, stakeholders) is almost at all levels of the design process. Source: Rajaonah, 2022, p. 33

C.1 The Scientific Démarche

We sometimes hear in conversation “We, in science, we...”, where “we” is a student, a teacher or a researcher in mathematics, engineering & technology, physics or computer science and the audience someone who comes from human and social sciences. And yet, history, literature and psychology (for example) are also sciences taught at university. Therefore, it may be that, even among researchers, there is a misconception concerning what science is.

The two first divisions (§ C.1.1 and § C.1.2) deal with science-related definitions in order to get things straight and establish a frame of reference for the present work.

C.1.1 General Definitions

C.1.1.a Science, Scientific

From a dictionary viewpoint, for example, Merriam-Webster⁴ or Collins⁵, science is defined as knowledge or a system of knowledge covering general truths or the operation of general laws especially as obtained and tested through scientific method or, merely, a body of facts learned by study or experience, whereas knowledge refers to understanding, comprehension. But regarding the value of truth, there are other viewpoints, more circumspect, for instance that science is “imperfect and fallible” and can “tolerate lack of truth,” it can be seen as “a practical way to increase our ability to predict and control the natural world, and does not carry the ambition of finding underlying ‘truths’ of nature” (Zimring, p. 59).

In a general way, it is admitted that science refers to bodies of knowledge and research to the practice aiming at increasing knowledge; it is also admitted that all academic areas have their bodies of knowledge. Science as practice can also be connected to characterizations of conduct, for example, rigorous



Figure 3 Al-Khwarizmi (pixabay.com)

⁴ Merriam-Webster.com Dictionary: <https://www.merriam-webster.com/>

⁵ Collins Online Dictionary: <https://www.collinsdictionary.com/>

science (Casedevall & Fang, 2016), cultural practice (Višňovský, 2020), or ethical conduct (Niemi, 2016).

Scientific can be seen as a “label” that qualifies concepts that are inherent in science, for example, “to apply a scientific method to test ideas about canoe history” (Luukkanen & Fitzhugh, 2020) or “all scientific explanations are tentative” (Clark et al., 2017); the word ‘scientific’ also applies to multitude of other concepts such as attitude, thinking and reasoning, or proof and evidence (e.g., the everyday scientific reasoning scale, Golumbic et al., 2023).

C.1.1.b Research

The Merriam-Webster dictionary provides the following definition: “investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new revised theories or laws⁶.”

C.1.1.c Discipline

Simply said, a discipline is a field of study⁵. Ferris (2004) said that science and discipline could be seen as interchangeable when they describe a particular means of knowing. But, to be less general, an academic discipline can be seen as a subject matter of teaching and research (e.g., Biglan, 1973a) or as, noticed by Krishnan (2009), a branch of science which has most of the following characteristics: a particular object of research (e.g., society) even though it can be in common with another discipline; a body of specialist knowledge referring to the object of research; theories and concepts which organize the accumulated knowledge; specific terminologies or a specific technical language adjusted to the object of research; specific research methods; and institutional manifestation (teachings, academic departments, professional associations).

Academicians tend to perpetuate the belief of a dichotomy between hard and soft sciences, which does not correspond to the spirit of the categorization by subject matter in academic areas proposed by Biglan (1973a, 1973b). Indeed, the studies that he carried out among scholars from a

⁶ <https://www.merriam-webster.com/dictionary/research>

university and a small college of North America to judge academic areas show that these areas could be characterized along three main dimensions which are the following:

i/Existence vs. absence of a clearly delineated paradigm (a paradigm referring to a body of theory to which all members of a field adhere according to Biglan who cited Thomas Kuhn⁷). This dimension was the most prominent (in terms of explanatory variance), it distinguishes areas such as physical and biological sciences on one hand of the axis from areas such as humanities and education sciences, on the other hand; hence Biglan's differentiation between hard, paradigmatic academic areas and soft, nonparadigmatic areas.

ii/Concern with application is a pure-applied dimension distinguishing disciplines that are concerned with practical application of their subject matter (e.g., education sciences, engineering sciences) from academic areas that are "pure" (e.g., mathematics, zoology).

iii/Concern with living systems as objects of study such as psychology and botany on one hand, vs. nonlife systems such as astronomy and computer science, on the other hand.

Disciplines have also cultural, at least, community-based dimensions; the persistent idea of hard vs. soft science based on a hypothetical order of value is one example, for instance, hard is good, soft is bad (see the review of Shapin, 2022); the similar idea of science vs. nonscience to demarcate academic areas is also an example of the cultural dimension of disciplines (see Zimring, 2019, for his brief history of science vs. nonscience).

C.1.1.d Interdisciplinarity

Tackling complex real-world problems (e.g., energy crisis, famine, pandemics, marine pollution, cyber-criminality, etc.) requires researchers to adopt a holistic view, cross the borders of disciplines, share knowledge and methods, and work together. In that context, interdisciplinarity is more than a "fashionable word" (to quote Pellegrino & Musy, 2017), it is a necessity. But interdisciplinarity can have several meanings: Rosenfield (1992) distinguished interdisciplinarity

⁷ Kuhn, T. S. (1962). *The structure of scientific revolutions*. University of Chicago Press: Chicago. <https://psycnet.apa.org/record/1962-35001-000> (accessed Jan. 23, 2023). Newtonian mechanics and Einstein's theory of relativity are paradigms of physics, the theory of evolution is a paradigm in biological sciences and behaviorism in psychology

from multidisciplinary and transdisciplinarity regarding the manner how researchers work together.

- Multidisciplinary work means that scientists work independently in parallel or sequentially from disciplinary-specific base to address common problem, and the results are brought together at the end, for example, in the form of separate chapters in a report.
- Interdisciplinarity means that scientists work jointly (they interact, coordinate, etc.) but research is still disciplinary specific based.
- Transdisciplinary work implies that scientists developed a shared approach and a common conceptual framework to solve the research problem that they have defined together. Transdisciplinarity provides a more comprehensive level of understanding (see Lawrence, 2010). It may include non-academic, societal actors (see Lawrence et al., 2022).

According to the above categorization, it is obvious that the best way for science to deal with major environmental and societal issues and contribute achieving the 17 sustainable development goals⁸ is transdisciplinarity.

C.1.1.e Technology and Innovation

The Collins dictionary⁵ says that “technology refers to methods, systems, and devices which are the result of scientific knowledge being used for practical purposes.” Not only science and technology are therefore interdependent, but also they are interdependent with innovation (Brooks, 1994). An innovation is “an idea, practice, or object that is perceived as new by an individual or other unit” (Rogers, 2003), and innovation is often associated with development (e.g., Silvestre & Țircă, 2019) or prosperity (e.g., EIC, 2022⁹). We said earlier that the students of today will be the innovators of tomorrow¹⁰; in fact, even though not all of them will be inventors, all, whatever their disciplines, could have a role in innovation, therefore on development and progress due to the mentioned above interdependencies. Precisely, with regard to the 17 sustainable development goals, Walsh, Murphy and Horan (2020) – who asserted that science,

⁸ Sustainable Development Goals: <https://sdgs.un.org/goals>

⁹ European Innovation Council (2022), *EIC 2023 Work Programme*, https://eic.ec.europa.eu/eic-2023-work-programme_en (accessed Feb. 03, 2023)

¹⁰ Rajaonah (2022), Human-centred research & design for inclusive mobility. Sections A & B, <https://hal.science/hal-03726812/>

technology and innovation were pillars of the United Nations 2030 agenda¹¹ – regrouped the sustainable goals into macro-goals (see below), which shows that the goals are not independent each other, neither are the scientific disciplines that underlie them; it also shows that innovation (i.e., new ideas, new practices or new technologies) is at all levels of sustainable development, and therefore concerns all academic disciplines.

- Goals 1–7 (i.e., no poverty, zero hunger; good health & well-being; quality education; gender equality; clean water & sanitation; affordable & clean energy) dedicated to the social pillars of sustainable development;
- Goals 8–12 (i.e., decent work & economic growth; industry; innovation & infrastructure; reduced inequalities; sustainable cities & community; responsible consumption & production) dedicated to the economy;
- Goals 13–15 (i.e., climate action; life below water; life on land) dedicated to the environment;
- Goals 16 and 17 (i.e., peace, justice & strong institutions; global partnerships for sustainable development) dedicated to governance.

C.1.1.f Research & Development (R&D)

The dictionary defines *research and development* (R&D) as being the “studies and tests that are done in order to design new or improved products”⁵ or the “part of a commercial company’s activity concerned with applying the results of scientific research to develop new products and improve existing one”⁴. But, regarding the definition of innovation, R&D is not only focused on technological products and processes.

According to the Frascati Manual 2015¹² published by the Organisation for Economic Co-operation and Development (OECD):

¹¹ The 2030 Agenda for Sustainable Development: <https://www.un.org/sustainabledevelopment/development-agenda/>

¹² OECD (2015). *Frascati Manual 2015: Guidelines for collecting and reporting data on research and experimental development*. The measurement of scientific, technological and innovation activities. Paris: OECD Publishing. <http://dx.doi.org/10.1787/9789264239012-en>

- Research and experimental development¹³ “comprise the creative and systematic work undertaken in order to increase the stock of knowledge—including knowledge on humankind, culture and society—and to devise new applications of available knowledge.”
- “R&D is found in the social sciences, humanities and the arts, as well as in the natural sciences and engineering.”
- A R&D activity necessarily: aims at new findings (novelty); develops new concepts or ideas that enhance existing knowledge (creativity); involves uncertainty about the final outcome in terms of results, costs, and/or time; is “conducted in a planned way, with records kept of both the process followed and the outcome (systematic); is transferable and/or reproducible, that is, an R&D project should result in the potential for the transfer of the knowledge, ensuring its use and allowing other researchers to reproduce the results as part of their own R&D activities.”
- There are three types of R&D activities:
 - Basic research, i.e., theoretical or experimental work carried out to acquire new knowledge of the underlying foundation of phenomena and facts, without any application in view;
 - Applied research, i.e., original research undertaken to acquire new knowledge but primarily directed towards a specific, practical aim; or
 - Experimental development, i.e., “systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes”; it is just a part of the product development process.

There are relationships between these three activities as it is shown in the following example retrieved from the Frascati Manual 2015 (an excellent document that should be read by all students).

- Example in language/linguistics:
 - Basic research: to study how different languages interact as they come into contact each another;

¹³ ‘Research and experimental development’ and ‘research and development’ are here both abbreviated as R&D

- Applied research: to analyse the underlying neurology of languages and language skills acquisition;
- Experimental development: to develop a tool for autism diagnosis.

C.1.1.g Technology Readiness and Other Scales

Some calls for project proposals – e.g., projects funded by Horizon Europe (the European Union’s research and innovation framework programme for 2021–2027¹⁴) – specify the required degree of development or maturity regarding the innovation of interest; it is often the Technology Readiness Level (TRL). This scale was invented in 1974 at the North American National Aeronautics and Space Administration (NASA) to assess the evolution of an idea from the first thought to the full deployment of a product¹⁵. Since then, the scale has been improved and formalized to provide a useful tool in R&D in general, it has even inspired the development of other scales (see Bruno et al., 2022 and Sprenkeling et al., 2022). Indeed, technology readiness alone is not sufficient to assess the maturity of the technology.

A human-centred perspective on R&D requires to consider the society, what Innovation Fund Denmark¹⁶ did by creating the Societal Readiness Level (SRL) scale that assesses the adaptation of a social or technical innovation to the society, as well as the social acceptance of innovations. The Legal Readiness Level (LRL) scale proposed by Bruno et al. (2022) considers a specific aspect of this adaptation to the society through the examination of the compliance of innovations with legal, regulatory and ethical issues. Sprenkeling et al. (2022) go beyond the readiness of innovations by aiming for their embeddedness in society. They propose a four-level tool named Social Embeddedness Levels (SEL) which connects technological and societal dimensions in the assessment of innovations during the development process. Societal dimensions concern the impact on the environment, stakeholders’ involvement, policy and regulations, and market and financial resources.

¹⁴ Horizon Europe: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en (accessed Feb. 8, 2023)

¹⁵ Jim Banke, NASA Aeronautics Research Mission Directorate, 2010 (page updated Aug. 7, 2017), Technology readiness Levels demystified. https://www.nasa.gov/topics/aeronautics/features/trl_demystified.html (accessed Feb. 8, 2023)

¹⁶ Innovation Fund Denmark: Innovation Fund Denmark: https://innovationsfonden.dk/sites/default/files/2019-03/societal_readiness_levels_-_srl.pdf (accessed Feb. 8, 2023)

Table 1 presents the nine levels of technological readiness (TRL), the nine levels of societal readiness (SRL), and the four levels of societal embeddedness (SEL).

Table 1. Three scales to measure the degree of maturity of innovations

Technology Readiness Levels TRL	Societal Readiness Levels SRL	Societal Embeddedness Levels SEL
TRL1—Basic principles observed	SRL1—Identification of problem and of societal readiness	SEL1—Exploration Societal aspects explored
TRL2—Technology concept formulated	SRL2—Formulation of problem, proposed solution(s) and potential impact, and	
TRL3—Experimental proof of concept	SRL3—Initial testing of proposed solution(s) together with relevant stakeholders	
TRL4—Technology validated in a lab	SRL4—Validation of proposed solution(s) through pilot testing in relevant environment	SEL2—Development Societal aspects assessed
TRL5—Technology validated in a relevant environment	SRL5—Validation of proposed solution(s) by relevant stakeholders in the area	
TRL6—Technology demonstrated in a relevant environment	SRL6—Solution(s) demonstrated in real world environment, with relevant	
TRL7—System prototype demonstration in an operational environment	SRL7—Refinement of project and/or solution and, if needed, retesting in real world	SEL3—Demonstration Societal aspects included in system
TRL8—System complete and qualified	SRL8—Proposed solution(s) as well as a plan for societal adaptation complete and	
TRL9—Actual system proven in an operational environment	SRL9—Actual solution proven in relevant environment	SEL4—Deployment Innovation proven in societal environment
Bruno et al. (2020); European Commission (2022)	Innovation Fund Denmark ¹⁷ ; Bruno et al. (2020)	Sprenkeling, Geerdink, Slob, & Geurts (2022)

¹⁷ <https://innovationsfonden.dk/en/about-innovation-fund-denmark>

Even though TRL and SRL are close when innovations are technological, they do not overlap, they remain two models of maturity (Bruno et al., 2022), while the examination of societal embeddedness cannot be done independently of the level of technological readiness (Sprenkeling et al., 2022).

C.1.2 The Basics

Science is about gathering facts, constructing explanations, and building knowledge. In that sense, it is obvious that most of academic disciplines fall under science and are thus concerned with the scientific *démarche*¹⁸.

C.1.2.a The Steps in Research

Whatever the discipline, scientific research generally follows the following path: observation of an issue or need to understand some phenomena or facts; definition of the research question; collection of data from experimentations, focus groups, surveys, computer-based simulations¹⁹, etc.; data analysis; interpretation; conclusions with regard to the research problem; return to knowledge and facts (in the form of new knowledge or new facts); new questions (**Figure 4**). It is worth noting that not only the results should be made public, but also the methodology used and, when possible, the data collected; the former contributes to increasing knowledge, the latter to enabling others to reproduce the study or carry out further analyses (we will come back to this in Section D). Hence the necessity to write up the methodology without leaving out a single detail.

¹⁸ <https://www.collinsdictionary.com/dictionary/english/demarche>

¹⁹ For example, the four-color conjecture of Francis Guthrie, formulated in 1852 (in the form that “every map drawn on a sheet of paper can be colored with only four colors in such a way that countries sharing a common border have different colors”, Appel & Haken, 1977, p. 108), was proven to be true in 1976, by a computer with a program written and many times modified by Appel and Haken since 1972

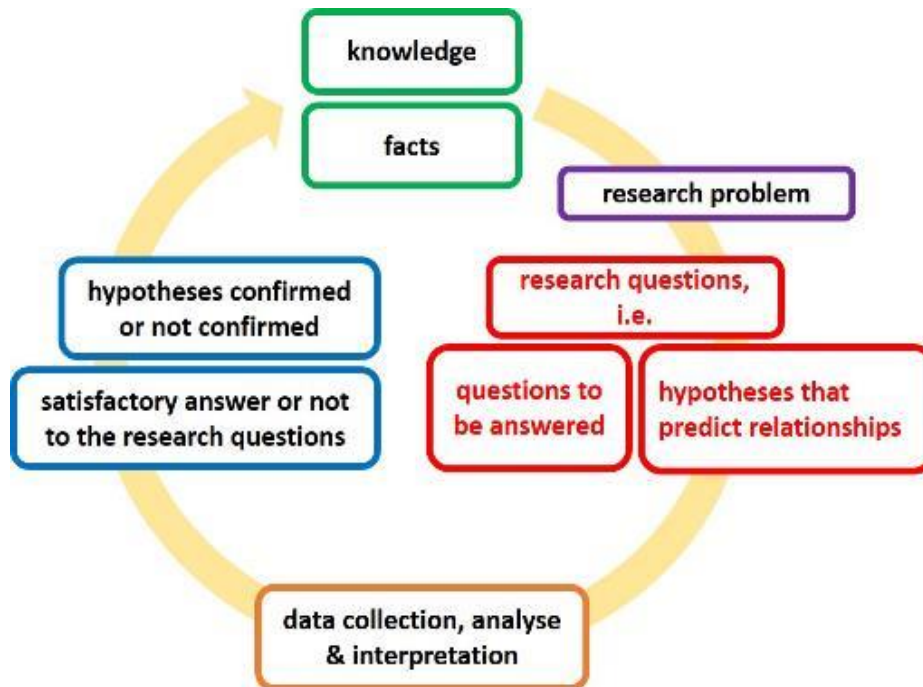


Figure 4 Doing science in a few words

C.1.2.b Exploration or Hypotheses

Research can be characterized in many ways:

- Qualitative vs. quantitative research or mixed research. According to Creswell and Creswell (2018):
 - In qualitative research, the researcher aims to explore or understand “the meaning individuals or groups ascribe to a social or human problem”;
 - In quantitative research, the researcher aims to test “objective theories by examining the relationship among variables”;
 - Mixed research involves both.
- Bernard (2006) clearly distinguished qualitative vs. quantitative data, and qualitative vs. quantitative analysis (**Table 2**).

Table 2. Qualitative vs. quantitative, the distinction with examples or explanations (Bernard, 2006, pp. 451-452)

		Data	
		Qualitative	Quantitative
Analysis	Qualitative	Qualitative analysis of qualitative data, e.g., interpretative studies of texts	Qualitative analysis of quantitative data, e.g., search for pattern using visualization methods like multidimensional scaling ²⁰
	Quantitative	Quantitative analysis of qualitative data, i.e., after having coded data such as words or images into numbers	Quantitative analysis of quantitative data, i.e., numerical or statistical analysis of numerical data

- Confirmatory vs. exploratory research. According to Taeger & Halliday (1998):
 - Confirmatory research aims to test *a priori* alternative hypotheses;
 - In exploratory research, the researcher attempt to generate some *a posteriori* hypotheses from the data set.
- Inductive vs. hypothetico-deductive approach²¹. According to Stebbins (2001):
 - Exploration is primarily inductive, while confirmation is primarily deductive; primarily, not exclusively, that is: when deductive thinking is used in exploratory research, it is rather within the researcher's "emerging theoretical framework" (not within established theory²²); and when inductive thinking is used in confirmatory studies, it is to confirm the researcher's "emergent generalizations," not to test a priori hypotheses.
 - Qualitative research is thus not confined to exploration: qualitative research can also be confirmatory. In fact, research [in human and social sciences] can be described as qualitative exploratory, qualitative confirmatory, quantitative exploratory, or quantitative confirmatory²³.

²⁰ See, for example, Ogden et al. (2017) who used qualitative analyses (multidimensional scaling, cluster analysis) of quantitative data (verbal statements who were sorted and rated) in a participatory study that aimed to identify the organizational actions required to ensure patient-centred care

²¹ Induction refers to "a form of reasoning, also called empirical induction, in which a general law or principle is inferred from particular instances that have been observed" (Colman, p. 373), whereas in deduction a particular conclusion is drawn from a set of premises (Blackburn, 2016, p. 122)

²² According to Jackson and Christensen (2014), "theory often refers to a generalization or set of generalizations that are used systematically to explain some phenomenon"

²³ Also, the qualitative approach is not confined to soft sciences ("soft" in accordance with the definition of Biglan, 1973a, 1973b), e.g., observational techniques are used in ethology (i.e., a branch of biology); and the quantitative approach is not reserved to hard sciences, e.g., hypothesis testing is often used in psychology

C.1.2.c Research Question

The research question helps the researcher along the path of the scientific démarche of which it is a part. Developing a good research question is even the most important part of the research process (Lipowski, 2008).

According to Cummings, Browner, and Hulley (2013), research questions are good if they can confirm, refute or extend previous findings, or provide new findings; and also they should be relevant to scientific knowledge and future research.

Research questions emerge from observed problems, or findings in owns' or others' prior studies. It requires that the researcher master the published literature in the scientific areas of interest, as well as the new trends, ideas and techniques.



Source:pixabay.com

Concretely, based on Creswell and Creswell (2018), research questions could be categorized into two categories:

- Research questions in qualitative research refer strictly speaking to questions to be answered by the research, they are neither objectives nor *a priori* hypotheses based on established theories. They comprise central research questions (one or two questions) and subquestions (no more than five to seven subquestions) following each central question. An example of central research question could be “How the personality of rail users can shape their safety behaviour in railway stations?” Creswell and Creswell recommend to:
 - focus the central question on a single phenomenon or concept;
 - begin the research questions rather with “*what*” and “*how*” than with “*why*” to restrain the researcher from thinking in terms of cause-and-effect relationships;
 - use exploratory verbs (e.g., to report, to describe, to discover, to generate, to seek to understand, to explore a process) and use them as nondirectional words (examples of “directional” verbs used in quantitative research are: to affect, to influence, to impact, to determine, to cause, to relate);
 - use open-ended questions, i.e., that do not provide a set of responses.

- Research questions and hypotheses in quantitative research refer to relationships among variables. For example, a research question could be “Can the theory of planned behaviour (e.g., Ajzen, 1991) explain the relationship between pedestrians’ self-confidence and their behaviour with regard to basic safety rules for crossing railway lines?”; a resulting hypothesis could be “The higher the level of pedestrians’ perceived self-confidence, the quicker the decision to cross the railway line.”

Creswell and Creswell (2018, pp. 137-) recommend to:

- Define the goal of the studies, both research questions and hypotheses depending on that goal: either i/**comparing groups** on an independent variable to see the impact on a dependent variable or ii/**relating variables**, i.e., relating one or more independent variables to one or more dependent variables, and iii/**describing responses** to the independent, mediating, or dependent variables. See below for more details on variables.
- Use the same pattern of words’ order in research question and hypotheses to ease the identification of major variables.

C.1.2.d Hypothesis

In a general way, a hypothesis is “a proposition as a supposition, rather than asserted that serves a tentative of explanation of certain facts. A hypothesis is “a prediction about a specific event or relationship between variables” (Creswell & Creswell, 2018, p. 52). Before going further, some clarifications about variables are provided by Creswell and Creswell (pp. 50–51):

- The **independent variable** (IV)—also named the experimental variable (which is varied or manipulated by the experimenter)—influences or affect the outcome of an experimental study. The **dependent variable** (DV) is the outcome or result of the influence of IV. A **predictor** or **antecedent variable** is used to predict an outcome of interest in a survey method study. An **intervening** or **mediating variable** transmits the effect of an IV on a DV²⁴. A **moderating variable** is a predictor variable that impacts on the relationship

²⁴ For example, trust in automation can be considered as a mediating variable standing between the level of automation of an industrial robot (IV) and the working partner’s reliance on the robot (DV)

between IV and DV (demographic variables such as age and gender are often considered as moderating variables instead of major independent variable).

Also referring to Creswell and Creswell (2018, p. 137):

- A null hypothesis “makes a prediction that in the general population, no relationship or no significant difference exists between groups on a variable”
- If the null hypothesis is rejected (i.e., the statistical test does not show relationship or significant difference between groups) then the alternative hypothesis is considered:
 - The directional alternative hypothesis (one-tailed) makes a directional prediction (e.g., higher, lower, more, less, etc.);
 - The nondirectional hypothesis (two-tailed): the direction is not specified.

C.2 Doing Science

This chapter described three types of research approaches – qualitative, quantitative, and mixed methods – more in detail than in the previous chapter. Let us (i) emphasize that one or other of these approaches is adopted at almost each phase of the process of designing human-centred technologies and human-centred socio-cyber-physical systems (see **Figure 2**); and (ii) recall that human-centrality is one of the pillars of Industry 5.0 (the others are sustainability and resilience) (see Breque, de Nul, & Petridis, 2021; Renda et al., 2022).

The choice of an approach mainly depends on the goal of research and the research question, rather than on the researcher’s discipline. Nevertheless, the choice may also depend on the researcher’s worldview, which is often attached to a discipline or a particular branch of a discipline, a worldview being a general philosophic orientation about the world, composed of beliefs and values acquired and shared through communities’ memberships (e.g., Creswell & Creswell, 2018; Duffy & Chenail, 2011; Yilmaz, 2013).

For example, the postpositivist worldview relies on a deterministic philosophy²⁵, hence the (positivist) researcher aims to “identify and assess the causes that influence outcomes” (Creswell

²⁵ Stanford Encyclopedia of Philosophy (<https://plato.stanford.edu/>). “Determinism: the world is governed by (or is under the sway of) determinism if and only if, given a specified way things are at a time *t*, the way things go thereafter is fixed as a matter of natural law”. There is the belief that “every event is necessitated by antecedent events and conditions together with the laws of nature.”

& Creswell, 2018), for instance through experimental designs. Another example of worldview is the constructivism: the researcher adopts the view that individuals and groups construct their own reality and knowledge, the key point is thus the meaning they make of their experiences and world; the goal of the researcher is then to “rely as much as possible on the participants’ views of the situation being studied” (Creswell & Creswell), for instance through interviews with open-ended questions, i.e., that do not provide a set of responses, the participants responding with their own words. Finally, mixed methods research that combines or mixes ideas from both qualitative and quantitative research Bernard (2006) is rather a matter of pragmatism, that is, “what is important and justified or ‘valid’ is what works in particular situations in practice” (Johnson & Christensen, 2014), the focus being on the research problem and the approaches to understand it (Creswell & Creswell, 2018). However that may be, the choice of data collection techniques may just depend on the availability of financial/time/human resources.

Each approach is described below with the data collection techniques that we think to be relevant to human-centred design (but some techniques are utilizable in qualitative and quantitative research, e.g., questionnaires).

C.2.1 Qualitative Research

C.2.1.a Purpose

Researchers who wish to have a deep understanding of a particular phenomenon or experience within a specific context are likely to adopt qualitative research, more precisely qualitative analysis of data (see **Table 2**). It can be characterized as follows:

- In-depth examination of the experience or perceptions of individuals, group/society phenomena, expectations, interests, indifference, hostility, etc. within a specific context, in short, any subject that may give rise to attitudes and behaviours in that context, which the researcher wants to understand without concern for generalization (Aspers & Corte, 2019; Creswell & Creswell, 2018; Flick, 2014; Ravitch & Carl, 2020; Thomas & Malgivy, 2011).

And according to Creswell and Creswell:

- Mainly in natural settings;
- Open-ended forms of data;

- Focus of the participants' meanings;
- Researchers' concern for how their personal background, culture and role may shape the direction of the study;
- Holistic perspective on the research problem.

C.2.1.b Data Collection Techniques

Data collection techniques for qualitative are almost always used in face-to-face interaction with the study community and the study participants, they focus on data collection at the sociocultural collective level and individual level, and through two possible ways: observation or interviewing that is, data are what the researcher sees or what is told to the researcher, respectively (Given, 2008, p. 520).

Focus Group

The focus group technique (FG) can be used at almost all levels of the human-centred design process (**Figure 2**).

- Need analysis (i.e., identification of the needs and expectations of the stakeholders involved in the design and deployment of the technology, they include the end users). For example, see Cano et al. (2023);
- Specifications (i.e., activity that includes the transcription of the needs and expectations into technical specifications). For example, see Demiris et al. (2006);
- Tests and evaluations of concepts and prototypes; for example, see Kinnaird and Romero (2010).

The goals of focus group discussions are to understand questions related to social interaction process, attitudes, opinions and experiences in specific groups and contexts, how knowledge and ideas develop and operate in a given cultural or group context (Ravitch & Carl, 2020, pp. 147–148). Exchanges and interactions enable them to debate controversial topics, for example, ethical issues of technologies (ethics being a questioning of moral standards²⁶) or other debatable topics. Discussions within focus groups are conducted by a skilled interviewer (also named moderator or

²⁶ See, for example: Ricoeur, 2000; Russ and Leguil (2012)

facilitator) whose role is to ask questions, prompt answers and manage the flow of talk (Scott, p. 252)

A focus group is relatively a small group: in addition to the moderator, it involves from three to about ten participants; the more sensitive the topic of discussion and/or the more vulnerable the participants, the more appropriate the smallness of the group size (e.g., Barbour, 2018; Ravitch & Carl, 2020; Smithson, 2008). Focus groups are not appropriate when the topics may be seen as personal or sensitive by the participants (Smithson, 2008).

Focus group discussions are audio- or video-recorded (video-recording also records the nonverbal aspects of a discussion), then transcribed, then coded (at least one coder to limit interpretation biases and errors) – for example with NVivo qualitative data analysis software²⁷ – and analysed. The use of a software to process qualitative data “enables a researcher to demonstrate the integrity, robustness, and therefore, trustworthiness of an investigation” (Given, 2008, p. 563), the latter being often questioned, especially by positivist researchers (e.g., Shenton, 2004) (and yet it is the trustworthiness of both qualitative and quantitative research that is challenging). Vandemeulebroucke et al. (2019) provide an example of analysis of focus group discussions about the ethical issues of socially assistive robots as perceived by older adults (target users). Duboz et al. (2022) used the technique of focus group for online discussions on the acceptance of connected and automated vehicles (also interesting, their paper provides in an annexe the script for the moderators).

Interviews

Focus group discussions is a form of interview, except that in the three forms of interview described in this chapter the interviewer addresses only one person, which is thus appropriate when dynamic between stakeholders is not essential or when there is no interest in group norms (e.g., Mack, et al., 2005). The goal of interviewers is to try eliciting information or expressions of opinion or belief from the participant, face-to-face or remotely, e.g., by telephone (e.g., Brinkmann, 2018). It is emphasized in the Sage encyclopedia of qualitative research methods (Given, 2008) that interviewing cannot be used in thinking that it would be the easiest way to do research, but it is a mistake; the qualities that interviewers should have are interest in the perspectives of other people

²⁷ <https://lumivero.com/products/nvivo/> (accessed March 24, 2023)

and the skill of listening (Patton, 2002). Whatever the form of interview, a document directs the interviewer, it is the interview guide (used in focus group discussions too), see Given (2008) and Patton (2002); it is also useful for the collection of reliable, comparable qualitative data (Bernard, 2006). The interview guide (or agenda) includes the questions or at least the topics to be explored during the interview, as well as instructions. The research question drives an interview, the goal of the set of questions is therefore to provide answers to the research question: the researcher has to have that in mind not to lose sight of the research question, hence the usefulness of the interview guide (e.g., Willig, 2013).



Source: Pixabay.com

Three forms of interviews are usually distinguished:

- Relatively unstructured interviews: suit to fieldwork where the interviewer cannot know in advance what is going to happen and who will be present, most of questions flow naturally like during a conversation from the immediate context (the participants may not even realize they are being questioned) i.e., they are not predetermined and vary with individuals and circumstances. Limits pointed out by Patton (2002) are i/the possible difficulty to organize and analyse the data, especially due to ii/the fact that this form of interview is the less systematic and comprehensive, and iii/conversational interviews are time consuming. Nevertheless, this form of interview can be used to characterize the context of use of a technology and identify users' needs, as well as during the test and evaluation phase, complementary to quantitative analysis. For example, see: Demirbilek and Demirkan (2004); Prange et al. (2015).
- Relatively structured interviews: the questions are exactly those of the interview guide and they are asked in the same standardized way for all respondents, which leads to answers that can be compared, even quantified (see Brinkmann, 2018). The interviewer cannot improvise, which is suitable when the researcher and the interviewer are not the same person, see Wood et al. (2003) who conducted a study comparing structured interviews with children conducted by a human interviewer vs. a robot interviewer. Structured interviewing is appropriate when the range of replies of the participants is well-known, when it is not the case, semi-structured interviews are better (Maguire, 2001).

- Semi-structured interviews are the most often used. Good questions are brief, simple, open, and should lead the participant to concrete descriptions rather than abstract reflections; Given (2008) adds that concrete descriptions are obtained with “what” and “how” questions (rather than with “why”). The interview guide specifies the order of questions (or topics) to be covered (Bernard, 2006), preferably moving from more public questions to more personal matters (Willig, 2013). Willig wrote that restating the participant’s comments showed that the interviewer had listened; besides, it is an opportunity to check mutual understanding. The master’s thesis of Navarrete describes the use of semi-structured interviews for user requirement elicitation in the human-centred design process (Navarrete, 2020).

Many authors (e.g., Bernard, 2006; Johnson & Christensen, 2004; Mack et al., 2005; Ravitch & Carl, 2020) consider that recording interviews (with permission) is very important and taking notes also. Recording involves transcription, essential for those who intend to carry out a non-superficial analysis of data: consider therefore the costly step of transcription before drawing the research design. In addition to audio- or video-records of the interview, taking notes (of participants’ behaviour, contextual cues, etc.) – when it is possible and when it does not distract the participants – may be useful for the debriefing that follows an interview, even more for data coding and analysis. The above-mentioned work of Navarrete (2020) is very useful to understand how to prepare semi-structured interviews, code and analyse data.

Questionnaires

According to de Leeuw (2008), self-administered questionnaires mainly differ from interviews by i/the absence of the interviewer (therefore no encouragement regarding motivation to answer and no extra-explanation) and ii/the fact that the respondents see the questions (which requires a particular attention regarding the formulation and presentation of the questions).

Moreover, interviews transcripts are qualitative (text), whereas questionnaires can deal with both qualitative and quantitative data and analysis; questionnaires are less costly (time and resource), a great deal of information can be collected in a short period of time from a lot of people, and they are appropriate for sensitive questions. But, along these advantages, Ravitch and Carl (2020) notice some disadvantages, among them: responses can be inaccurate because of the bias of social

desirability²⁸; it may happen that not many thought goes into the responses, which can affect their accuracy; understanding of the questions may differ from the researcher's point of view.

A qualitative questionnaire (i.e., with open-ended questions) is appropriate in a study involving a few participants; in case of a survey involving thousands of respondents, a particular attention should be devoted to the issue of dealing with open-ended questions, long before the choice of a research design, even though the survey combines open-ended and closed-ended questions. Rahimi and Tafazoli (2022) conducted a study with 12 participants to assess the usability of language massive open online courses; they used a qualitative questionnaire and their paper explains how they analysed the responses.

Observation

According to the Sage encyclopedia of qualitative research methods, observation implies that the researchers (whether their research is qualitative or quantitative or between the extremes) collect impressions using their senses, especially looking and listening, in a systematic way to learn about a phenomenon of interest (Given, 2008, p. 573). Concretely, observation consists in watching people and recording what they do and say. It is carried out either in a natural setting (e.g., observing students in a classroom, pedestrians at a railway crossing, athletes during training) or in the laboratory (for example, to assess the usability of a prototype by observing participants interacting with it). The researcher either participates in the activity of the person-s being studied (participative observation) or does not participate (non participative observation)²⁹. See the study of Beede et al. (2020) to understand the use of a large-scale participative observation within the framework of human-centred evaluation of a deep-learning-based system (in total more than 150 observations were carried out). Combined with observation, the think-aloud technique may be useful in the evaluation phase of the human-centred design process; it consists in asking the participant to think aloud—i.e., “to verbalize his or her thoughts and why he or she is performing certain actions” while interacting with or using the object of evaluation (Burnes, 2018); see Rose et al. (2018) who used this technique with teens in usability testing. Like for focus group

²⁸ Piedmont, R.L. (2014). Social Desirability Bias. In: Michalos, A.C. (eds), *Encyclopedia of quality of life and well-being research*. Dordrecht, The Netherlands: Springer. https://doi.org/10.1007/978-94-007-0753-5_2746

²⁹ The literature is not homogeneous regarding ‘participative vs. non-participative observation’ and ‘participant vs. non-participant observation’

discussions and semi-structured and informal interviews, data (participants' comments and behaviour, researcher's field notes) should be coded before analysis.

C.2.2 Quantitative Research

According to Bernard (2006), the concept of 'quantitative' in research refers to quantitative data (i.e., quantifiable, countable, measurable) or quantitative analysis (e.g., statistical analysis) or both (see **Table 2**). This chapter focuses on quantitative analysis of both qualitative and quantitative data.

C.2.2.a Purpose

The purpose of carrying out research with quantitative analysis is to describe situations or phenomena, establish relationships between variables³⁰, or attempt to explain causal relationships between variables (Mertler, 2016, p. 108), which can be translated into the following types of research question: descriptive, comparative, associative relationship, and causal relationship questions (see Creswell & Creswell, 2018; Onwuegbuzie & Leech 2006).

The focus on only some variables makes quantitative research different from the holistic nature of qualitative research.

Figure 5 recaps that the research question determines the appropriate method: globally, surveys enable the researchers to answer their questions about "a quantitative description of trends, attitudes, and opinions of a population, or tests for associations among variables of a population, by studying a sample of that population", while experiments³¹ enable the researcher to answer questions about the impact of manipulated variables on outcomes of interest after having kept all other variables constant (Creswell & Creswell, 2018, p. 147). In any quantitative research statistical procedures are used for data analysis and interpretation (Mertler, 2016): descriptive studies consist of the summary of quantitative and qualitative data (mean, standard deviation,

³⁰ "A variable is a characteristic or condition that changes or has different values for different individuals" (Gravetter & Forzano, 2016, p. 4)

³¹ A laboratory experiment is "a research method by which researchers create controllable environments to test hypotheses" (Perderson, J. (2017). Laboratory experiments. In M. Allen (Ed.), *The SAGE Encyclopedia of Communication Research Methods*, Volume 2. Thousand Oaks, CA: SAGE Publications). A field experiment is conducted in a real-life setting (Johnson & Christensen, 2014)

frequency distribution, etc.) and graphics, whereas the others include inferential statistics that allow the researcher to make generalizations about the population from which a sample is selected (Gravetter & Forzano, 2016).

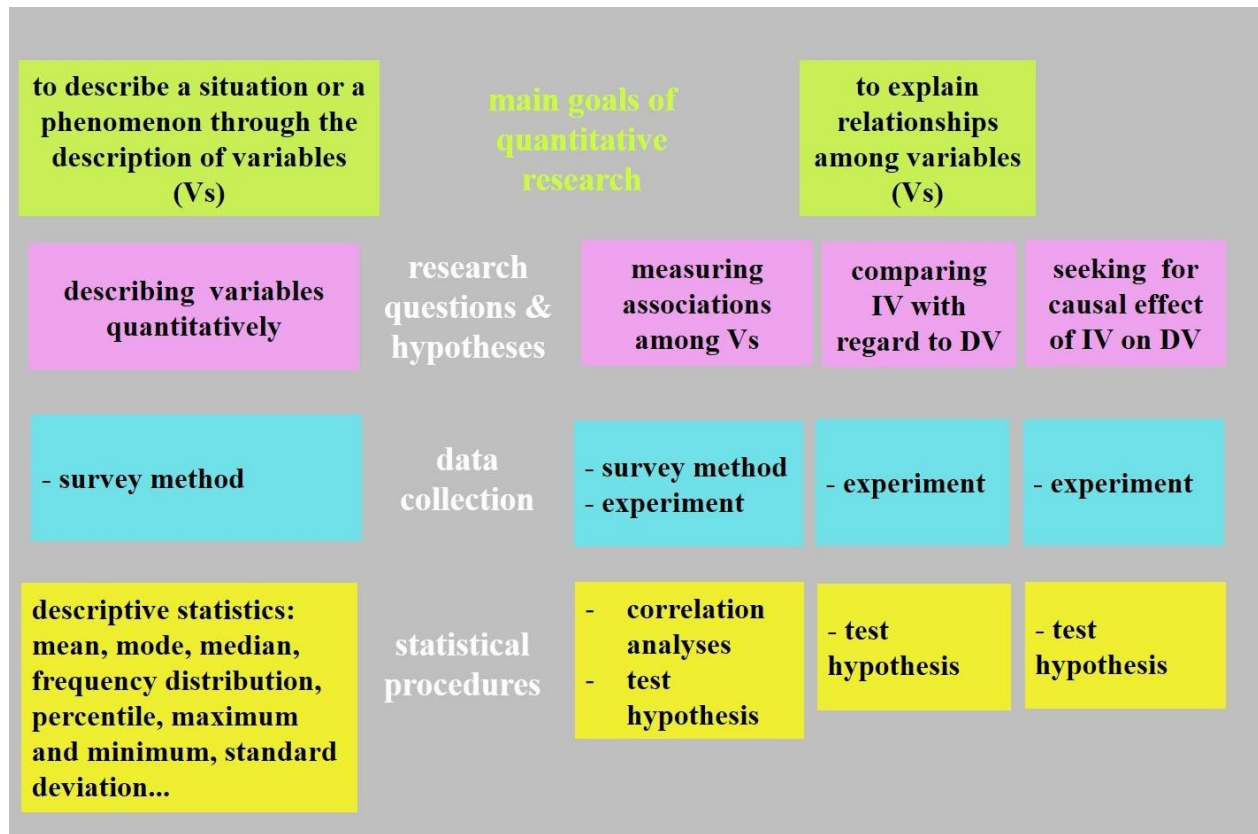


Figure 5 Quantitative research, schematically

C.2.2.b Quantitative Research Designs

Experimental designs

Creswell and Creswell (2018, p. 165) characterize experimental designs³² as following:

- True experiments with experimental group(s) and control group, and random assignment of the participants to groups; depending on authors, true experiments also include random selection, i.e., “the process of choosing, in random fashion, individuals for participation in

³² Research design is the outline, plan or strategy used to answer the research question (Johnson & Christensen, 2014)

a research study, such that every member of the population has an equal chance of being selected to be a member of the sample” (Mertler, 2016, p. 127).

- Quasi-experimental design with control and experimental groups, and partial or total lack of random assignment;
- Pre-experimental design with no control group;
- Single-subject design ($N=1$) for which the behaviour of a single individual is observed over time;
- Between-group design: comparison of two or more groups;
- Within-group design: repeated measures for different conditions at different times within a group.

Survey Designs

Survey research can be characterized as following, according to Mertler (2016, pp. 112-116):

- Use of a probability sampling technique³³ to ensure that the sample represents the population as accurately as possible;
- Descriptive surveys to describe the characteristics of a sample at one point in time;
- Cross-sectional surveys to examine the characteristics of and differences among several samples measured at one point in time;
- Longitudinal surveys to study the same group of participants at different points in time.

C.2.2.c Data Collection in Quantitative Research

Data are collected from the measurement of dependent variables in order to obtain data of objective nature. Besides, many techniques of data collection mentioned for qualitative research can be used to collect data of subjective nature to be analysed quantitatively (after having coded qualitative data into quantity if necessary). **Exploiting data of subjective nature is fundamental in the process of human-centred design.** This is how the use of questionnaires is frequent in experimental studies that assess human and technology interactions; indeed, the nature of the information gathered with a questionnaire is subjective even though the responses are in terms of numbers.

³³ See, for example, Cumming, 1990; Goodman and Kish, 1950

The so-called Likert scales are ordinal scales responses that can be ranked or ordered; but it is not possible to measure the distance between the values, the intervals between values cannot thus be presumed to be equal, which implies that means cannot be calculated, which limits inferential statistical procedures to non-parametric tests such as Chi-square or Mann-Whitney U tests (Allen Seaman, 2017; Jamieson, 2004). The use of a visual analog scale enables the researcher to measure perceptions, it is more practical in terms of data analysis and provides unambiguous results.

The study of Tsironis, Katsanos, and Xenos (2016) about the evaluation of MOOC platforms is an example of gathering data of both objective and subjective nature in an experimental study:

- Goal: to evaluate the usability of MOOC platforms;
- IV: three types of MOOC platform (within-group design);
- Collected data include:
 - o Data collected automatically during the task: task duration, success at finding correct webpage and/or controlling to perform the required action, in order to derive measures of effectiveness and efficiency, the latter being DVs,
 - o Responses from 0 to 100 to the ten items of the questionnaire of perceived usability (another DV) for each MOOC platform.

The study of Shangavi, Zhang, and Jeon (2023) is another example:

- Goal: to examine the impact of auditory display urgency and the driver's affective state on driving task performance and quality in semi-automated cars with a study with a simulator.
- IVs:
 - o Affect: induced anger vs. neutral affect (between-group),
 - o Auditory warning of requested take over, with various frequencies and numbers of repetitions, i.e., a total of 9 alerts (within-group).
- DVs:
 - o Take over performance and quality through: speed, deceleration, steering angle, lane change direction (driving task data) and eye-tracking data regarding the use of mirrors (number of glances, gaze duration),
 - o Scores at an affective state questionnaire (7-point Likert-type scale).

To recap, in the two above-mentioned studies the data collected were of both objective and subjective nature, but both data were quantitative. However, even though both quantitative and qualitative data are produced in a study, it is not necessarily a mixed methods study.

C.2.3 Mixed Methods Research

To recap the two previous chapters, quantitative research most often focuses on a few factors, even one factor, and aims to generalize to populations the objective (outsider) look at of samples of these populations, while qualitative research focuses on groups of individuals – even on one individual – who construct their own reality and knowledge, and aims to investigate this subjective reality (without a goal of generalization).

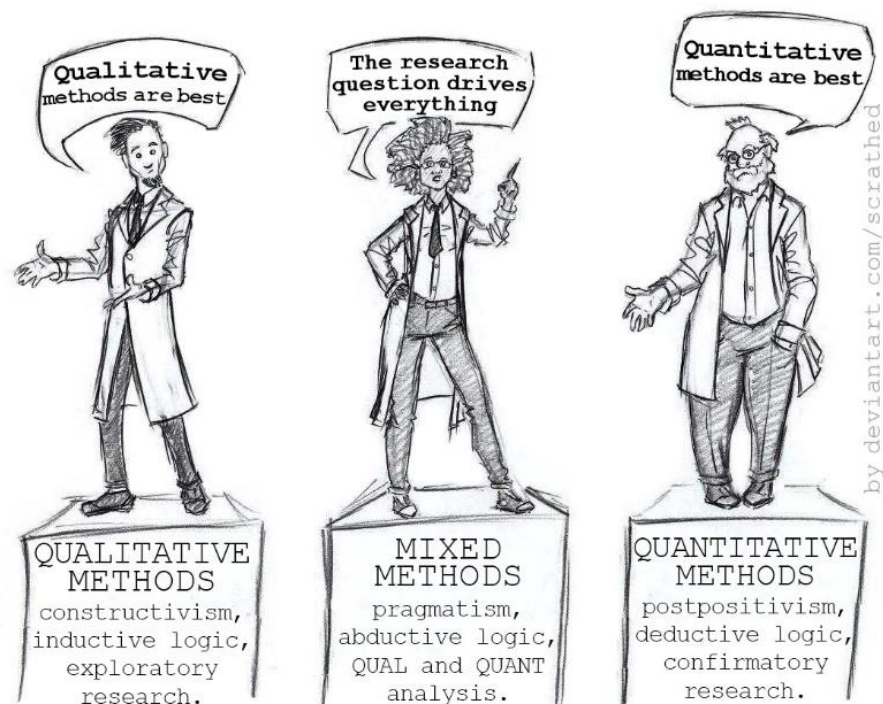


Figure 6. “The simple juxtaposition of the three paradigms”. Illustration created by Scrathed (<https://www.deviantart.com/scrathed>), licensed under cc by-nc 3.0, and retrieved from Mueller (2019)

The mixed research paradigm combines or mixes perspectives of both qualitative and quantitative research Bernard (2006); it is neither the simple gathering of quantitative data nor the simple

addition of qualitative data to a quantitative design: integration or combination rather addition is the main characteristics of mixed methods research (Creswell, 2015).

According to Creswell & Creswell (2018), the research question directly addresses this mixing, that is, a mixed method study ideally contains at least a qualitative research question, a quantitative question and a mixed methods question, the latter addressing the integration or combination of the qualitative and quantitative data, at least in convergent mixed methods research. Indeed, Creswell and Creswell distinguished three kinds of mixed methods:

- Explanatory sequential mixed methods: quantitative research first, then qualitative research in order to explain the quantitative data;
- Exploratory sequential mixed methods: qualitative research in first to explore the views of participants, the resulting information being used to design the quantitative research study, for example, to build an instrument that is appropriate to the sample under study or to specify variables;
- Convergent mixed methods: quantitative and qualitative data are merged for a comprehensive investigation of the research problem.

The research of Côté-Leclerc et al. (2017) – which goal was to investigate how playing adapted sports did affect the quality of life of people with mobility limitations and which was carried out with 34 wheelchair users with paraplegia – was a mixed methods sequential explanatory study. The quantitative step consisted in comparing the perceived quality of life of wheelchair users playing an adapted sport with people without disabilities; the qualitative step included 10 individual semi-structured interviews (respondents were a sample of the 34 wheelchair users).

The research of Schröder et al. (2018) – which goal was to investigate the mobility behaviour of a rural population of Germany in terms of medical consultations—was a mixed methods exploratory study. The qualitative step consisted of four focus groups and one telephone-interview (40 persons in total) dedicated to get in-depth opinion from representatives affiliated with mobility in the rural district under study; the quantitative step consisted in a survey questionnaire that was built from the results of the previous study, and distributed to a representative random sample of 1000 adults living in the district.

The research of Rouleau et al. (2022) – which goal was to quantitatively and qualitatively assess the acceptability of a virtual patient simulation used in nursing continuous education – was a convergent mixed methods study. The first step was quantitative, based on an online 80-item survey completed after having consulted the virtual patient ($N=27$), while the second step was qualitative – but complementary to the survey – based on a focus group with five of the 27 nurses, both types of data being analysed independently; the third step consisted in integrating the quantitative and qualitative results to compare them. See the following references cited by Rouleau et al. to better understand the concept of integration: Fetters et al. (2013), Johnson et al. (2019), and Pluye et al. (2018).

C.3 Conclusion

Section C is a view over the concepts of science and research which are useful to the students who wish to deal with the design of human-centred technologies and services, not only for designing inclusive mobility, but also all human-centred technologies and services at the time of Industry 5.0.

This section is far from being exhaustive. For example, validity has not been described earlier, even though both quantitative and qualitative research are concerned with validity (even though what the concept covers is different because the matter of generalization does not concern qualitative studies).

According to Mertler (2016, pp. 138–140), internal validity in quantitative research refers to “the degree to which measured differences on the dependent variable are a direct result of the manipulation of the independent variable, whereas external validity refers to “the extent to which results of particular study is generalizable, or applicable, to other groups or settings.” Bernard (2006) provides a more global definition of validity, in social sciences, it refers to “the accuracy and trustworthiness of instruments, data, and findings” (p. 53). See also Whitemore et al. (2001) for an in-depth discussion about validity in qualitative research.

Validity, trustworthiness, integrity, and so on, all have to see with ethical research, which is the topic of *Section D—Ethical considerations*.

C.4 Acknowledgments

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