CHARACTERIZATION OF THE STUDENT PERCEPTION OF THE CONCEPT OF FLEXIBILITY IN THE MANUFACTURING DOMAIN: HIGHLIGHTING THE PATTERNS OF EFFECTIVE LEARNING

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Abstract

The word “flexibility” is often abused and not univocally understood within the manufacturing science domain and in particular in the context of industrial automation. Since the raise of industrial robots in the 1960’s, different researchers and practitioners have been using such a common word with different meanings. This has generated a very articulated concept, spanning from capability of a system to increase the production volumes to ability to handle product mix variation. Several authors have tried to count the current meanings of such a word in manufacturing and someone arrived to more than 50 [1]. In spite of this fuzziness in both the definition and scope, the concept of flexibility remain one of the cornerstones in the curriculum of industrial and production engineers, and it appears in many courses along the bachelor and master studies. The apparent paradox that higher education institutions have to teach things that are not even well-defined and agreed in the scientific world is, in fact, quite a usual practice. In order to clarify what is, or should be, learnt this work analyzes first the established literature to extract a “working” characterization of the flexibility concept. The resulting understanding is then used to represent the experts’ perception of the topic which in turn is used as ideal level of understanding that a student should achieve her/himself when studying such a concept.

The second phase of the work aims at disclosing and classifying the multifaceted perceptions of flexibility that two different classes of industrial engineering students have after two courses in which the focal concept of manufacturing flexibility has been presented using two different approaches. The research is based on a phenomenographic analysis of a series of well-designed interviews to the students [2]. The collected data have consequently been structured in a finite set of clusters according of: (1) the level of understanding of the key concept (as expressed in the Bloom’s taxonomy [3]) and (2) the nature of the shown knowledge (as presented in the SOLO taxonomy [4]). The classification is then the basis for defining an epistemological sound approach to develop suitable teaching and learning activities to ensure optimal acquisition of the concept of flexibility.

Keywords: Flexibility, Industrial Automation, Phenomenography.

1 INTRODUCTION

The modern higher education organizations are facing an increasingly dynamic environment: students with different background and specific requirements, changing pedagogical means and global competition are only some of the emerging trends that are shaping future universities. This is even more dramatic in the technology domain where a more and more rapid process of innovation kills continuously the use of competencies and equipment. Consequently, in order to keep an effective and high quality education offer, the main focus of well-designed engineering programs and courses must shift from knowing a particular embodiment of a given technology towards having more soft skills like being able to search the information by oneself and to look critically at them, along with decide, plan and execute own formation endeavors or sounds delegation of responsibilities.

Traditional approaches, still in use in many university courses, offer lectures and lone textbook study. This “transmissive pedagogy” is based on the assumption that student are like boxes that can be filled with notions simply by exposing them to knowledge. This is as far from the truth as possible! Students have different background, motivations and inclination towards the learning process. A better characterization of such aspects is necessary to design effective learning moments that must act in different moment of the learning process [5, 6].
As an answer to the above requirements a more holistic approach based on facilitating good learning by letting the students experience the studied object in different context or with different embodiments has been proposed. Variation is thus the key to effective learning [7]. In other words the learners can build up reliable knowledge by disclosing the pattern of variation of the studied phenomena. Knowing the spectrum of student perception of a given phenomenon is thus the starting point for good course design.

The work presented in this paper is a phenomenographic study of the perception that production engineering students, at the end of two different courses, have of the concept of flexibility in manufacturing science. The following paragraph provides an overview of the analysed subject that can serve the reader as blueprint to go through the work and eventually understanding the findings

2 BACKGROUND

2.1 Pedagogical Supporting constructs

The analysis presented in this paper has been carried out using a phenomenological approach. Such a methodology focus on the study of the variation in ways people experience the construct and phenomena in a discipline. The assessment of such perceptions is not done in closed lab and on controlled variable, but is rather based on how the researcher engage with the people analysed. Phenomenographers focus on how a certain set of people experience a given phenomenon, defined as second-order perspective (studying the world as seen), rather than the phenomenon itself which instead is a first-order perspective (studying the world as such) [2, 8]. Consequently, the result is not a quantitative measure of people knowledge, but a taxonomy that can capture salient aspects of the variation with which a particular phenomenon is understood. These salient aspects, in turn, can be exploited to expose possibilities to improve the learning experience.

One of the important variables in determining the way students perceive the studied object is the cognitive level of complexity of their thinking in relation with the topic. Simple ability to remember a formula and mechanically put numbers in it is not an insurance that the student has grasped the underlying meaning of such relation and that he/she will be able to apply it in unknown situation. The static cognitive domain can be classified for example with the famous Bloom’s taxonomy [3] which depicts the development of intellectual skills related to a topic through the following six stages:

1. **Knowledge**: Recall data or information
2. **Comprehension**: Understand the meaning, translation, interpolation, and interpretation of instructions and problems. State a problem in one’s own words.
3. **Application**: Use a concept in a new situation or unprompted use of an abstraction. Applies what was learned in the classroom into novel situations in the work place.
4. **Analysis**: Separates material or concepts into component parts so that its organizational structure may be understood. Distinguishes between facts and inferences.
5. **Synthesis**: Builds a structure or pattern from diverse elements. Put parts together to form a whole, with emphasis on creating a new meaning or structure.
6. **Evaluation**: Make judgments about the value of ideas or materials.

The pattern towards high level of understanding is another important dimension of a phenomenographic analysis. As disclosed in the SOLO taxonomy, such patterns usually involve the following phases:

I. Quantitative phase
   1. Pre-structural: students only understand the subject at the individual word level, usually miss the point and uses too simple way of thinking about it.
   2. Uni-structural: students’ understanding focuses on only one relevant aspect of the subject.
   3. Multi-structural: students’ understanding focuses on several relevant aspects, but is treated as independent object and concepts.

II. Qualitative phase
   4. Relational: different aspects of students’ understandings have been integrated into a coherent body of knowledge.
   5. Extended Abstract: the integrated body of knowledge can be transformed into the higher level of abstract and be generalized to a new topic in the subject.
These constructs have been shortly recapped hereby as they have been very useful synthesis tools to analyze and troubleshoot the results of the focal analysis and thus to help the structuring of the research findings presented in this paper.

2.2 Flexibility in manufacturing: an expert understanding

As seen above, phenomenography aims at disclosing the variation of students’ perception of a given phenomenon. From this perspective, a successful learning process should bring the student from a little (if not none) initial understanding of the topic taught, to a level of awareness similar to the one of an expert in the field [8]. In order to understand the result of this work it is therefore necessary to briefly introduce the concept of manufacturing flexibility as it is nowadays understood and taught.

As it was also pointed out in the introduction “flexibility” is a perfect prototype of buzzword that finds its place in many different definitions belonging to several technical disciplines. The average student of production or industrial engineering will meet this word also in many others domains: Design theory, factory planning, manufacturing, decision making The common denominator among all these perspective is that flexibility is an attribute that makes a system able to cope with uncertainty and change. This also means the ease of modification and absence of irreversible rigid commitments. Being a concept linked to potential change, unlike system performance it is difficult to observe and measure [9]. As noticed by many scholars [10, 11], flexibility is in general not well defined and understood in the scientific word, yet it is a critical aspect for the competitiveness of a company and thus it must be a cornerstone in the education of every engineer.

In manufacturing science the concept of flexibility is in general understood as the capability to reconfigure manufacturing resources in order to continue producing efficiently different products in response to, or to prompt, changes in the system’s environment [1]. The introduction of industrial robots to handle welding in automotive industry has put the stress on such concept that is still nowadays the object of intensive research efforts. Flexibility allows organization to achieve Economies of Scope in their manufacturing processes [12].

Flexibility can be applied to many aspects of the manufacturing domain. The following list presents a series of definition (not univocally accepted!) as reported by [1]:

- **Machine flexibility** refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another.
- **Material handling flexibility** is its ability to move different part types efficiently for proper positioning and processing through the manufacturing facility it serves.
- **Operation flexibility** of a part refers to its ability to be produced in different ways.
- **Process flexibility** of a manufacturing system relates to the set of part types that the system can produce without major setups.
- **Product flexibility** is the ease with which new parts can be added or substituted for existing parts.
- **Routing flexibility** of a manufacturing system is its ability to produce a part by alternate routes through the system.
- **Volume flexibility** of a manufacturing system is its ability to be operated profitably at different overall output levels.
- **Expansion flexibility** of a manufacturing system is the ease with which its capacity and capability can be increased when needed.
- **Program flexibility** is the ability of the system to run virtually untended for a long enough period.
- **Production flexibility** is the universe of part types that the manufacturing system can produce without adding major capital equipment.
- **Market flexibility** is the ease with which the manufacturing system can adapt to a changing market environment.

The list above gives the idea of the wideness of the topic. All the aspects and their possible correlation and mutual influences along with their impact on the company performance and strategies should be understood by production engineers. In view of this it is clear that the concept of flexibility stretches far out of the boundaries of the single company involving the whole production network. Flexibility must be understood and taught as a mindset to be applied to cope with turbulent conditions.

Finally, another challenge in teaching such a concept is that the word flexibility is very common in everyday language, so when students meet it in technical jargon they might have some bias.
3 METHOD

In line with the phenomenographic approach [13] the study has been conducted through the notes taken during a series of interviews with the students which have followed two specific courses that were dealing with some aspect of the focal concept analysed in this work: flexibility in manufacturing science. Both the courses had 1 credit equivalent (26.6 hours) of content and workload related to manufacturing flexibility. Given the different nature and purposes of the courses the topic of flexibility was presented to the students using two different approaches.

The first group attended a course in Production Automation [14] at KTH Royal Institute of Technology in Stockholm, Sweden (hence only KTH). The course was held in the spring 2013. There were a total of 35 students of which 23 took part to the interviews used in this work. The approach used in such a course was “hands-on”. The students were given tutoring lectures on how to implement automatic operations on different kind of machines, and they were then assessed through lab activities where the teaching staff evaluated if their system were or not working correctly according to the given instructions. From now on in this paper this group will be referred as “Automation Group”.

The second group attended a course in Integrated Production [15] with focus on Assembly system design at KTH in the autumn 2012. There were a total of 37 students of which 29 took part to the interviews used in this work. For this course the approach was based on direct lectures and final exam made of open questions. This group will hence be referred to as “Assembly Group”.

The two groups of students had different ages in term of years spent at the university: the Automation Groups includes students in the second year of their bachelor degree, while the Assembly Group includes students in the first year of their master degree (typically with one and an half more years of university experience). Both the groups of students belong to the programme of Industrial Engineering, so within the boundaries of such a discipline one might say that they have similar backgrounds.

After the successful completion of the course the students that agreed to participate to this study have been interviewed in an informal way. Students were left free to initiate and steer the discussion, and they were only stimulated by the analyst if required. This process only finished when the interviewed had nothing more to add and a common understanding of her/his thoughts was achieved with the interviewer. There was not a structured set of questions, but the discussions focused around the following two open questions:

- What is flexibility?
- How can flexibility be beneficial for a manufacturing organization?

Each discussion has been different from the others: some have focused on equipment, some on economic benefit or strategic advantages and so on. The resulting two corresponding dimensions have been then the basis to implement a matrix of perceptions, which in turn has been used to cluster the students according to their level of understanding.

The categories represent the perceptions that different clusters of people have of the phenomenon: from misconception of people without experience, to basic partial understanding until the sophisticated vision of experts. The resulting clusters can be then arranged in a hierarchical structure that goes under the name of outcome space of the studied concept. The consequent awareness on how people perceive such phenomenon can be used as basis to devise strategies able to bring students to a perception that is more and more close to the one of people considered masterful in the specific field. Finally it is important to remark that the researchers’ personal awareness of the phenomenon is left aside as in this kind of study the only focus is the subjects’ ones [16].

Finally, it is important to underline that this study has not measured external factors influencing the learning process of each students. For example it is quite safe to say that students that devotes an higher time on task will anyway reach an higher level of understanding of the topic, and that this is independent from the teaching approach. Still, the main assumption, and the generative idea behind this work is that a well-designed set of teaching and learning activities, coming from a rational measure of student perception of a given topic, will contribute to efficiently bringing students to a superior knowledge level.
4 RESULTS

4.1 Frame of reference

The perception of an articulated concept such as manufacturing flexibility is necessarily a quite complex object which can be presented and understood in many different ways. For this reason, as discussed above (see § 3. Method) in order to depict the results of this analysis, all the answers have been collapsed in two main dimensions: WHAT is manufacturing flexibility? WHEN and WHY can manufacturing flexibility be useful for an organization? This latter question aims at investigating the perceived domain of flexibility. The first dimension can be considered internal to the construct and the second external.

In line with the phenomenographic methodology the reference for such analysis is the expert perception of Flexibility rather than a precise definition (for a brief introduction to such perception the reader can refer to the § 2. Background). While the traditional ways of assessing knowledge focus on correct repetition of covered concepts, in this analysis the aim is to gather the big picture. For instance, students that cannot repeat the definition of product flexibility might have a better perception of the concept than students which have memorized it.

4.2 Students perceptions

The scrutiny of the interviews’ content has disclosed a quite broad spectrum of student perception of both the internal and external dimension. Perceptions are quite personal, but it is possible to identify common patterns in the answers that allow to classify the students in well-defined groups. In reference to the internal dimension (What is Flexibility?) the clusterization process resulted in four groups. The related aggregated perceptions can be described in order of increasing sophistication as follows.

Flexibility is:

- …Set of technical solutions for increasing some capability of a manufacturing organization
- …Way of efficiently harmonizing demanding product requirements with production resources in order to achieve economies of scope
- …Capability of well-designed production installation, to cope with changing conditions in different contexts
- …Mind-set that must shape the design of organizations which find their competitive advantage in rapidly adapt and react to external changes

The external dimension (Which is the domain of Flexibility?) is perceived in 4 different ways. A first, rather small, group of students shows belief that Flexibility only affects the production system (1). Some students then integrated this with reference to the product (2). Most of the students perceive flexibility to have impact on the company as a whole (3) or on part of the network where a given organization does business (4).

4.3 Taxonomy of the perceptions

The combination of the internal and external dimensions allows providing a complete description of the students’ ways of experiencing the focal concept of Flexibility. The subsequent list describes in details the identified taxonomy, while Table1 at the end of the paragraph introduces a graphical summary of such findings:

1. Conception 1. Simple technical: the few students in this cluster are only able to describe some isolated technical applications of the concept. This quantitative knowledge is often not well linked to other knowledge, thus appears rather uni-structural. They perceive flexibility as something limited to the improvement of the production system. If stimulated by the interviewer they can broaden their perspective including the product as the main cause for the flexibility demand. Nevertheless it appears rather clearly that their perception of the domain is quite limited and static: pre-structural according to the SOLO taxonomy.

2. Conception 2. Advanced technical: this group of students is very similar to the previous one in relation to their perception of the domain. In spite of this poor understanding of the when and why, the group seems more conscious about the what. In particular, there is a significant difference in the way they experience the concept of flexibility. Learners in this cluster, in fact, refer to flexibility not as a fixed set of technical solutions, but they rather describe flexibility as an approach to make the production system more efficient and effective given some
demanding initial conditions. The students here are implicitly aware of how flexibility enables the exploitation of economies of scope for the organization.

3. Conception 3. Technical Economical: this cluster is characterized by a broader perception of the domain of flexibility. In particular the concept of economies of scope is explicitly mentioned and well-placed in the context of possible synergies between product and production system. The knowledge in this cluster is multi-structural and the learners are aware of the technical and economical limitations of most of the concept's instantiations.

4. Conception 4. Strategic: the students in this group have a significantly broader and most sophisticated perception of both the concept of flexibility and its domain. The showed a reliable acquisition of the quantitative knowledge and revealed personal development of such constructs into a qualitative framework. In particular, all the technical and economical aspect are known and correctly framed within the organization as a whole. Flexibility is a global strategy to face turbulent market, and can be implemented at any level in the organization. The technical manufacturing solutions are correctly referred to objects in the domain of strategy. The consequent alignment of manufacturing strategy with the overall strategy of a firm is well understood and explained.

5. Conception 5. Holistic. The perception in the previous cluster is generally recognized as excellent way of experiencing the concept of flexibility by production engineers. Nevertheless, as seen in the background of this work, from the general point of view of the whole organization flexibility must be understood as the driver for the development of successful companies which operate in turbulent markets. A few students clearly showed they were partially aware of this, so even if the actual courses were not aimed at directly teaching such aspects, they acquired such perception by integrating what they learnt in their previous knowledge.

<table>
<thead>
<tr>
<th>The domain of Flexibility is…</th>
<th>Production System</th>
<th>Product and Production System</th>
<th>The Company as a whole</th>
<th>The company and the network</th>
</tr>
</thead>
<tbody>
<tr>
<td>...Set of technical solutions for increasing some capability of a manufacturing organization</td>
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<td>...mind-set that must shape the design of organizations which find their competitive advantage in rapidly adapt and react to external changes</td>
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The following Chart 1 completes the description of the survey’s results introducing the quantitative and qualitative data regarding distribution of the students across the inferred set of clusters.

Chart 1 Distribution of the students' perception of the flexibility concept across the two focal courses

5 CONCLUSION AND DISCUSSION

Flexibility is a very broad topic: it is impossible to cover in a single course all the single instantiations provided by the industrial domain. Consequently, when teaching flexibility, the focus is on the basic concepts leading towards the exploitation of economies of scope at all the level of the organization and beyond. Nevertheless, in the engineering domain, the learning is tightly linked to the real applications, thus the courses analysed provided many different examples of how flexibility is applied in industry. Students which have shown the simplest “Conception 1” are quite attached to such examples. They have not really abstracted the concept beyond these industrial installations.

Putting together such single installations through a correct understanding of the technical patterns is the gateway to the “Conception 2”. The students must be made aware that the solutions shown for increasing volume or product flexibility are based on the same principle even if different. Well-designed lectures and stimuli from the teacher should suffice in addressing the learners to acquire this conception.

Expanding the domain from the simple production system to the combination of production system and product is the key to achieve the “Conception 3”. This step is fundamental to fully grasp the critical concept of economies of scope in manufacturing. Exposition to different approaches to product design can enable such transition. Modular design vs integral design is an example. Examples of DF-X methods are also valid for this purpose.

“Conception 4” and “Conception 5” lies in the area of qualitative knowledge. Students must engage in complex project work or in discussions that involves the strategic aspects of business to acquire such level. For example, Customer Order Decoupling Point reasoning can provide an initial framework for such a perception to be acquired. Nevertheless, the achievement of such level can be achieved only if the students are able to relate the specific knowledge about flexibility with other knowledge in production science. Such level must thus be considered more as a programme objective rather than something acquirable with a single course.
The clear pattern depicted in words above is represented in the following Table 2, where the arrows put in evidence the possible patterns of evolution towards “expert-like” perception.

Table 2 Summary of the envisaged evolution of the students’ perception of the Flexibility concept and domain

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<thead>
<tr>
<th>Flexibility is...</th>
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The average better performance of the Automation Group (see Chart 1) suggests that providing a series of concrete “hands-on” problems can be beneficial: traditional transmissive methods appear less effective in this field.

The inferred taxonomy is based on a solid, but still limited amount of interviews. The learners that participated to the survey are quite homogeneously distributed when it comes to previous knowledge and background: this might hide some parts of the perception’s spectrum. Another source of error might be that the results have been interpreted by a reduced number of analysts. In view of this a further and broader validation of the inferred taxonomy would require to test more learners in different situations. Finally it is important to remark that the process of learning is complex and affected by many parameters that have been not considered in the study. Time on task and learning style among the others might have a huge impact on the process. A set of experiments where such parameters are controlled is therefore envisaged as necessary development towards the validation of the proposed classification.

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