Experiences of the SICAP Research Seeding in the Development of Soft Skills

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Abstract. The research seeding in applied sciences (SICAP) has the determination to improve specific skills but also develop soft skills in the Mechanical and Electrical Engineering students from the Pascual Bravo University Institution. One of that specific skills is machine and product design. On this occasion are shown activities from mechanical conceptual design resolved by work groups, following some elements from Cross Methodology (only the stages tree of objective, Functional analysis, Morphological diagram and weighted objectives) mixed whit traditional research methodologies, all joint whit activities that allow to conduct experiments, make decisions, team work, time management, develop communications and creative skills. The specific skills were evaluated by the finished of the conceptual design but the acquisition of soft skills was evaluated using a survey, as result the competences that most favor the methodology for designing prototypes in the SICAP research seedling are decision-making and communication with the work group and between colleagues.

Keywords: Soft skills · Machine and product design · Cross

1 Introduction

Economics and society always need qualified engineers and researchers [1], the increasing complexity of engineering systems, the expectations and demands of job market from engineers and the status quo of engineering faculties are considered, it is clearly seen that today, engineers need to get broader interdisciplinary training [2], this develop of this skills has been created the necessity of restructuring engineering education, [3].

Sönmez [2] states that engineering programs must demonstrate that their students attain the following outcomes: 1. An ability to apply knowledge of mathematics, science, and engineering, 2. An ability to design and conduct experiments, as well as to analyse and interpret data, 3. An ability to design a system, component, or process to meet desired needs, 4. An ability to function on multidisciplinary teams, 5. An ability to identify, formulate, and solve engineering problems, 6. An understanding of professional and ethical responsibility, 7. An ability to communicate effectively, 8. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context, 9. A recognition of the need for

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and an ability to engage in lifelong learning, 10. A knowledge of contemporary issues, 11. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

It is clearly seen that today, engineers need to get broader interdisciplinary training, to be able to adapt to the technological innovations and to succeed in a globally competitive business world [2].

The research seeding in applied sciences (SICAP) has the determination to improve specific skills but also develop soft skills in the Mechanical and Electrical Engineering students from the Pascual Bravo University Institution, whit the aim to training for complex engineering activities and improve self-learning skills and team work.

One of specific skills is machine and product design, the designs problems are addressed following some steps and stages clearly defined by Nigel Cross (From Cross methodology only the stages tree of objective, Functional analysis, Morphological diagram and weighted objectives) mixed whit traditional research methodologies, all with the goal of the conceptual design in this case.

In the conceptual design, the first stage is product specifications, then alternative solutions are originated and, after they are evaluating. The most convenient one is chosen. The conceptual design phases involve an abstraction exercise to find the essential problems, establish functional structures, look for work principles (Technically spoken), among others, all this are specific skills from electrical or mechanical designer in a quantitative and very technical way, but also other transversal knowledge and skills are necessary.

Some of those transversal or soft skills are the ability to work as a team, responsibility, honesty, and proactive attitudes when solving problems, which undoubtedly serve to generate innovative ideas and drive the growth of the organization.

On this occasion are shown activities from mechanical conceptual design resolved by work groups between 3 and 4 students, following some elements of the Cross Methodology but whit activities that allow to conduct experiments, make decisions, team work, time management, develop communications and creative skills.

The specific skills were evaluated by the finished of the conceptual design but the acquisition of soft skills was evaluated using a survey. This survey allows to evaluate the proposed methodology by the SICAP seeding coordinating team.

2 Methodology

The seeding research, is a group of training, learning and inventiveness made up of students, teachers and/or graduates who wish to carry out formative research. In the meetings learn to investigate, have the opportunity to connect with reality and contribute to improve it. The SICAP research seeding has a group of undergraduate students at the technological level (associate level) and engineering level (bachelor of Science level), who have had only one training course in research at the study program, so the work in SICAP, is the first investigative experience. Likewise, because they are from the first undergraduate semesters, their practical experience in design is scarce or nonexistent. whereby carrying out a project presents difficulties with the research center, due to the lack of this experience.

In addition, an engineering design project, as shown in Fig. 1 is difficult to fit into the basic research or applied research dimension, which creates a gap in the methodology to develop.

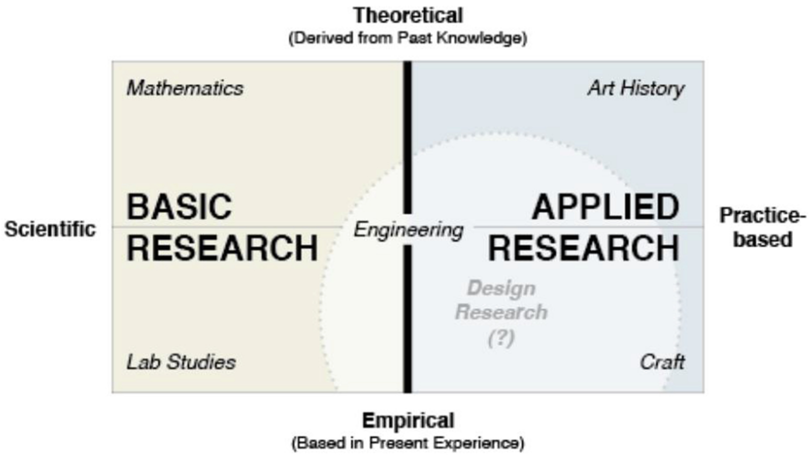

Fig. 1. Kinds of research. Source: [4]

The difficulties (a work team with no research experience and an uncertain methodology for project development), led the seeding coordinating team to develop a proposal that allow the project documentation to be done with a hybrid between the traditional model of the structure of the project. Research paper and a methodological development model based on engineering product design. For this, the methodology of Nigel Cross is taken.

Cross [5], poses a strategic approach to the design process supported by a set of methods applicable in its different stages. The initial proposal is a four-stage model, as shown in Fig. 2. Exploration, generation, evaluation and communication, which represents the actions that designers have to do, by the nature of the design. The communication, is the essential activity of the design, is “the production of a final description of the artifact” [5], which ends as a proposal ready for its manufacture (a final design proposal). Prior to this, the design proposal is evaluated by comparing it with the goals, constraints and criteria of the design approach in an iterative manner with the generation of solution proposals, which arise from the generation of a concept by the designers, as a result of an exploration of an ill-defined problem.

Cross [6], addresses the concept of an poorly defined problem, starting from the establishment of a dichotomy between well defined and poorly defined problems, which is summarized in Table 1. These poorly defined problems are those that should be approach the designers, because a product must be achieved, whose restrictions and criteria must be defined during the design process. Therefore, designers problems do not have a definitive formulation, may contain inconsistencies, may be dependent on the solution and the proposed solution may be a means to understand the problem and not be a definitive solution to the problem. Because of this, designers tend to focus on

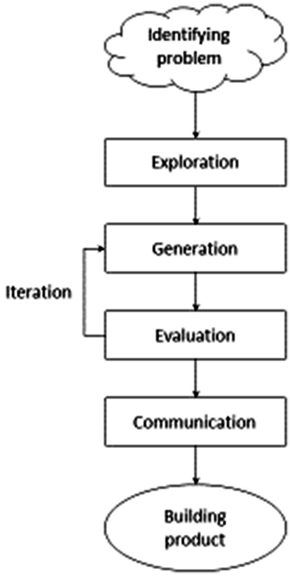

Fig. 2. Initial Cross model proposal. Adapted from [5].

the solution, contrary to what scientists tend to focus on the problem, with which designers use solution conjectures as ways to explore and understand the problem.

Therefore, the main competence of the designers, according to Cross, is to continuously manage and control the design processes. For this competition, it is necessary to develop some elements of competence, such as: teamwork, time management, creative thinking and effective decision making.

For Cross [5–9], the design process model with which the coevolution of the problem is developed and its respective solution, as shown in Fig. 3., consists in making an analysis of the complete problem to return it subproblems that leads to a process of synthesis of subsolution that then incorporates it into a complete solution.

Then Cross, is extending its model to an 8-stage model, based on the model of Michael French [10], as shown in Fig. 4, which establishes a method for each of them, which are presented in Fig. 5.

The first stage is the identification of opportunities, with which the opportunity to generate a new or improved product is identified and defined. The method is the creation of user scenarios. Then it continues with the clarification of objectives, which consists in establishing precisely what is to be obtained. These objectives are expressed in a vague and general way, because the problem is poorly defined.

Identifying and prioritizing the objectives becomes essential, which is why Cross proposes to use the objective tree at this stage. The third stage is the establishment of functions. It consists of determining what the product should do to achieve the objectives set out above, for which, Cross recommends and develops the application of functional analysis.

Table 1. Problems well and poorly defined. Adapted from [5]

Well defined problems	Poorly defined problems
There is a formulation of the problem with clear goals	There is no definitive formulation of the problem. At the beginning, the goals are vague and many restrictions and criteria are unknown
The formulation of the problem does not have inconsistencies, to arrive at a correct solution	Any formulation of the problem may contain inconsistencies. Only in the solution can many conflicts and inconsistencies be resolved
The formulation of the problem, under rules or known forms lead to the right solution	The formulations of the problem depend on the solution. It is difficult to formulate an approach to a problem without implicitly or explicitly referring to a concept of solution
The restrictions and criteria are completely defined in the formulation to the problem so that the solution is appropriate	La propuesta de soluciones es una forma de entender el problema. Muchas restricciones y criterios surgen como resultado de la evaluación de propuestas de solución
There is only one objective solution to the problem, which avoids ambiguity	There is no definitive solution to the problem. Different solutions can be equally valid answers to the initial problem, so there is no objective evaluation of true or false, it can only be appropriate or inappropriate

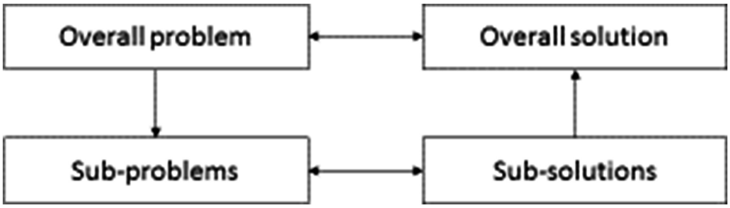

Fig. 3. Cross design process model. Adapted from [5]

The fourth stage is the requirement setting, which establishes the limits within which a design proposal is acceptable as a solution. For this, Cross proposes a method of specification of the performance, based on defining the degree of generality of the specifications and subsequently establishing conditions of the product from the functional analysis. In the fifth stage the characteristics of the product are determined from the specifications.

It is about physically configuring the product so that it performs its functions correctly. To determine the attributes of the product from the specifications, the QFD is proposed, to establish a list of requirements given by all the interested parties of the project. Once a set of characteristics is available, the generation of alternatives continues, starting from the establishment of different combinations or ways of arranging the elements to obtain valid products.

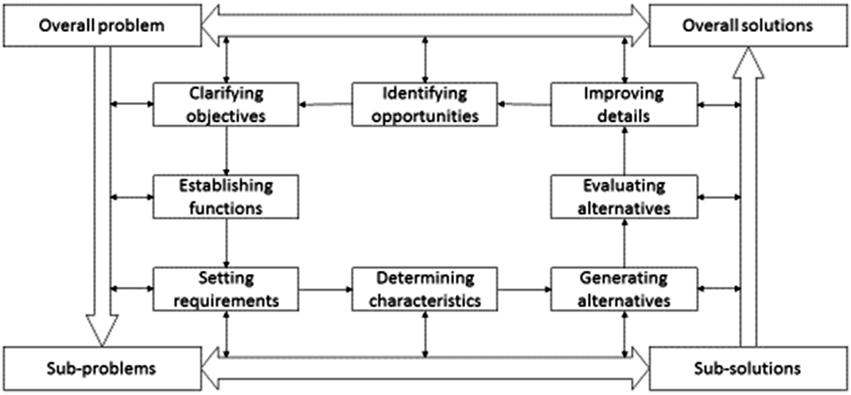

Fig. 4. Cross model and French model. Adapted from [5]

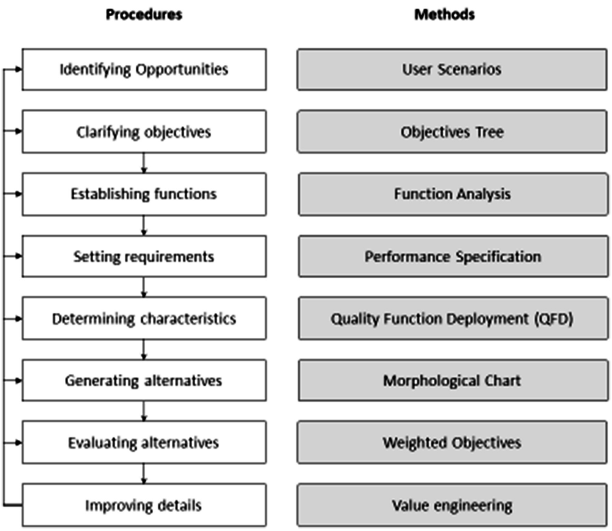

Fig. 5. Stages and design methods. Adapted from [5]

One way to generate a lot of alternatives is to identify different ways of fulfilling each of the functions and then combine them. This method calls it a morphological diagram. Then, in the seventh stage, we proceed to select the best of the alternatives from the point of view of the design objectives. It studies how each alternative works according to the functions and determines the best overall performance.

The method proposed by Cross is that of weighted objectives. As a final step, the improvement of details, Cross makes a consideration about value engineering, which seeks to improve the cost-value of products, by reducing costs and adding value to the product, depending on social contexts, cultural, technological, environmental, psychological and sociological with which the product is valued

For implementation in the SICAP research seeding, as shown in Fig. 6, previous scenarios created by the coordinating team are established, to avoid dispersion in the work of the students and the tree methods of objectives and analysis are adopted of functions, to reach the subproblems and the subsolutions and then, is proceed to work with the morphological diagram and the weighted objectives to arrive at a preliminary conceptual solution.

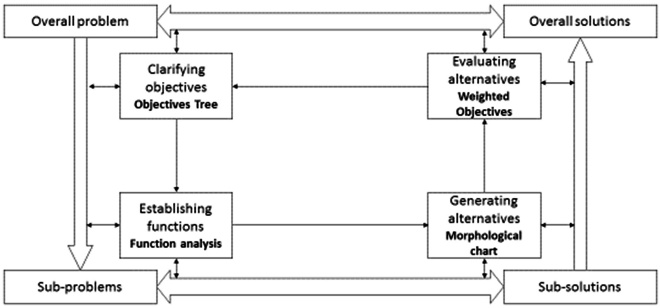

Fig. 6. Methodological model for the SICAP seeding

3 Results

For the academic semester of implementation of the strategy, a challenge of designing a technological product was proposed to the students of the line of research in Product Design, this challenge had to be faced and resolved in working groups of three or four students.

The main objective of the project was for each team to develop the solution to the Engineering challenge. The solution consisted in a conceptual design of a machine. This design had to be developed in an academic semester (16 weeks of classes) and during this process, 11 meetings were held between the seeding coordination team and the working groups.

The systematization of these activities was carried out in a digital template developed by the coordinator of the SICAP research seeding. The template used contains the main elements of the research methodology, such as: the problem statement, the justification, the objectives, the theoretical framework, the results of the project and conclusions.

Regarding the methodology chapter, some elements of the Product Development Methodology of Nigel Cross were adopted. Specifically, the stages of objective analysis, function analysis, generation of alternatives (through a morphological diagram), evaluation of alternatives (through weighted objectives) and selection of the best alternative were used.

According to Table 2, it can be seen that during the first session of the SICAP research seeding meetings, the students were explained what the challenge was, but also discussed the aspects to be taken into account for the formulation of the Research Problem. This first deliverable was agreed that it should be done in two weeks of work.

Table 2. Shows the relationship between work weeks and project deliverables for each of the student groups

Sesions	Week	Product
1	1	Approach of the challenge and approach of the problem
2	3	Justification
3	5	Goals
4	6	Theoretical framework
5	9	Methodology (Analysis of objectives and definition of design specifications)
6	10	Methodology (Analysis of functions)
7	11	Methodology (Generation of alternatives through a morphological diagram)
8	12	Methodology (Evaluation of alternatives by set goals)
9	13	Methodology (Selection of the best alternative)
10	14	Results and conclusions
11	16	Final delivery of the project

For the third week of the semester, a 2nd session was held, there was discussed what related to the justification of a research problem. For the elaboration of the justification, a period of two weeks was agreed. The 3rd session was held in the 5th week of the semester, and the formulation of the general objective and specific objectives was analyzed. For the elaboration of the objectives a period of one week was agreed.

For the fourth session, the topic of the theoretical framework was discussed. This was carried out during the 4th week of the semester. In the theoretical framework, the importance of respecting intellectual property rights through the use of referencing standards was highlighted. For the elaboration of the theoretical framework, a period of 3 weeks was established.

As previously mentioned, for the Project methodology, it was decided to use some elements of the product design method of Nigel Cross. In this sense, during the 9th week of the semester, the objectives analysis and design specifications were discussed with the students. This activity was carried out in the 5th meeting of the SICAP research seeding.

For the 10th week, the 6th meeting was held between the Seed Coordinator and the students. In that session the function analysis was carried out. This activity was carried out for a week.

In the 11th week of the semester, another element of the Cross Method was analyzed, which is known as the generation of alternatives. The generation of alternatives was carried out using a morphological diagram. The deadline for students to perform this activity was one week.

For week 12 of the semester, the 8th session was held. During that week the evaluation of the alternatives was carried out using the strategy of the weighted objectives. The next stage of the methodology, that is, the selection of the best alternative was made during week 13 of the semester. A one-week delivery time was set for this task.

In week 14 of the semester, the 10th seedling meeting was held. For this session, the results and conclusions of the project were defined. A delivery period of two weeks was agreed.

Finally, in session 11, which was held during the 16th week of the semester, each work team delivered their digitized project in the template adopted by the SICAP research seeding. During the last session, the difficulties encountered in the development of the project and the relevant aspects of the strategy used were discussed. For this, a survey was conducted.

At the first meeting of the SICAP research seeding, 14 students attended the Mechanical and Electrical Engineering, of different levels of training. Four work teams were formed: 2 teams of 4 students and 2 teams of 3 students. The challenge proposed for the SICAP research seeding coordination team was to design a solid waste collection robot on the beaches. For this challenge, it was requested to deliver the solution through a conceptual design.

On the first day of the meeting, the deliverables were agreed upon, the working methodology in the seedbed and the dates of each meeting. To take control of attendance of the participants, it was agreed to use meeting minutes.

Table 2 shows the number of students who participated in each SICAP research seeding meeting and the percentage of participants compared to the total number of participants.

It can be seen from Table 3, that during the 11 scheduled meetings there was a high participation of the students. The lowest percentage of participation was 86% in weeks 3 and 10, this shows a high commitment of students to the project.

Table 3. Relationship between week, students attending the meetings and percentage of participants

Week	Students number	Percentage of students who attended the meeting (%)
1	14	100
3	12	86
5	14	100
6	14	100
9	13	93
10	12	86
11	14	100
12	14	100
13	13	93
14	14	100
16	14	100

Table 4 shows the week of the academic semester, the deliverable or product, the term for the deliverable, the number of groups that met the deadline and the percentage of compliance with the total of groups.

Table 4. Relationship between week, students attending the meetings and percentage of participants

Week	Product	Term for the deliverable (in weeks)	Number of groups that met the delivery deadline	Percentage of compliance (%)
1	Approach of the challenge and approach of the problem	2	3	75
3	Justification	2	3	75
5	Goals	1	4	100
6	Theoretical framework	3	4	100
9	Methodology (Analysis of objectives and definition of design specifications)	1	4	100
10	Methodology (Analysis of functions)	1	3	75
11	Methodology (Generation of alternatives through a morphological diagram)	1	4	100
12	Methodology (Evaluation of alternatives by set goals)	1	3	75
13	Methodology (Selection of the best alternative)	1	4	100
14	Results and conclusions	1	4	100
16	Final delivery of the project	2	4	100

Based on Table 4, it can be seen that the lowest level of compliance with the term for deliverables was 75%. This was essentially due to the difficulty that some groups had in adequately posing the problem, given that it was a design challenge. The same happened when the subject of justification was addressed. These two chapters of the project were of the most complex to elaborate on the students.

In the case of the analysis of functions and the evaluation of alternatives, only one group reported having difficulties to understand and apply the strategy in their project.

In general, the students evidenced through their deliveries and the different meetings responsibility towards the deadlines, but also affinity for teamwork

The specific skills were evaluated by the finished of the conceptual design but the acquisition of soft skills was evaluated using a survey. The survey was posed the following questions:

1. Considers that the Cross methodology used in the conceptual design of the prototype encourages teamwork.

In Fig. 7, it is observed that in 25% of the cases, the respondents considered that the Cross methodology always encouraged teamwork, in 58.3% almost always and only in 16.7% considered that sometimes I did it. As a result, it can be considered that among the respondents, 83% consider that the Cross methodology contributes to the ability to work as a team.

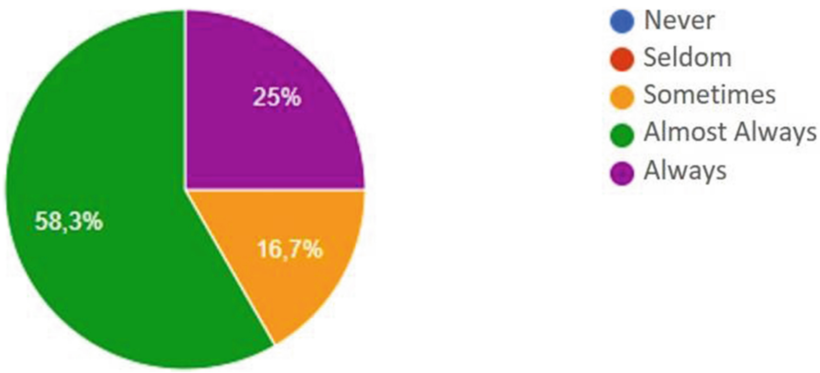

Fig. 7. Answers to teamwork

2. It considers that the Cross methodology used in the conceptual design of the prototype encourages the communication of its working group and among the other colleagues.

As can be seen in Fig. 8, all the respondents found that the Cross methodology encouraged communication in the working group, since half considered that it always did and the other half that almost always did.

Fig. 8. Answers to the communication of the working group

3. Consider that the Cross methodology used in the conceptual design of the prototype helps in the proper administration of time.

In view of the adequate administration of time, it can be seen in Fig. 9, that the response shows a favorability, although it is susceptible of improvement. Only 41.7% considered that it always contributed to the administration of time, while 33.3% considered that sometimes, and even 8.3% considered that their contribution is poor to time management.

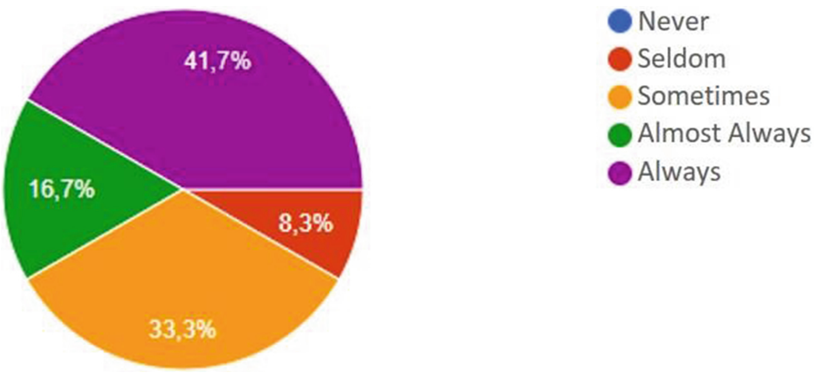

Fig. 9. Answers to time management

4. Considers that the Cross methodology used in the conceptual design of the prototype contributes to the development of creativity and innovation.

In Fig. 10, it can be observed that in a high percentage of the respondents, they considered that the Cross methodology contributes to the development of creativity and innovation, since, 83.4% of the population said that always or almost I always did it.

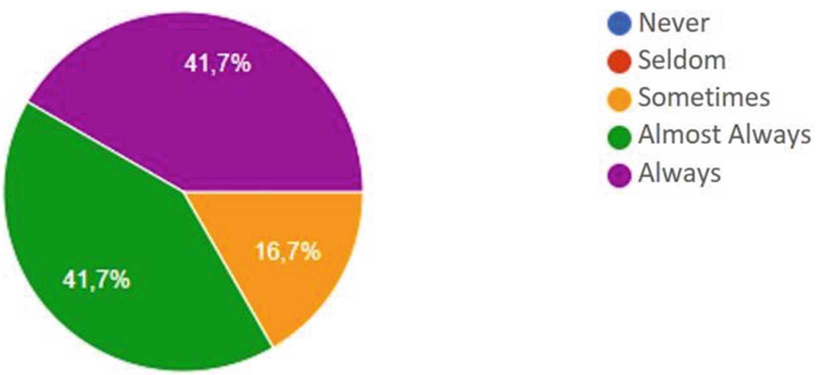

Fig. 10. Responses to the development of creativity and innovation

5. Considers that the Cross methodology used in the conceptual design of the prototype encourages scientific rigor in the development of projects.

Faced with the use of scientific rigor in the development of projects, the respondents, in 75%, found that it favored them relatively high, while 25% considered that they did it very rarely. This indicates that this competition needs to be improved a little more (see Fig. 11).

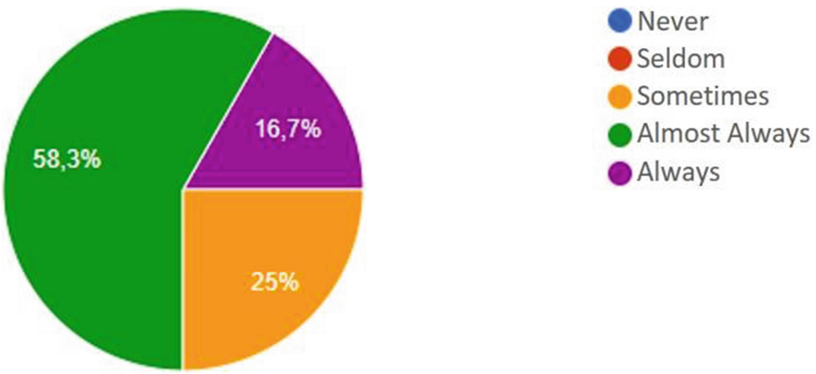

Fig. 11. Responses to scientific rigor in the development of projects

6. Considers that the Cross methodology used in the conceptual design of the prototype helps to improve interpersonal relationships with his work group, the other classmates and the team of teachers.

Regarding the improvement in interpersonal relations with the work group (Fig. 12), with the other group colleagues and the teaching team, it requires a better strategy, since, 41.7% of the respondents considered that the methodology only sometimes it favored him. 33.3% considered that they always did it and 25%, almost always.

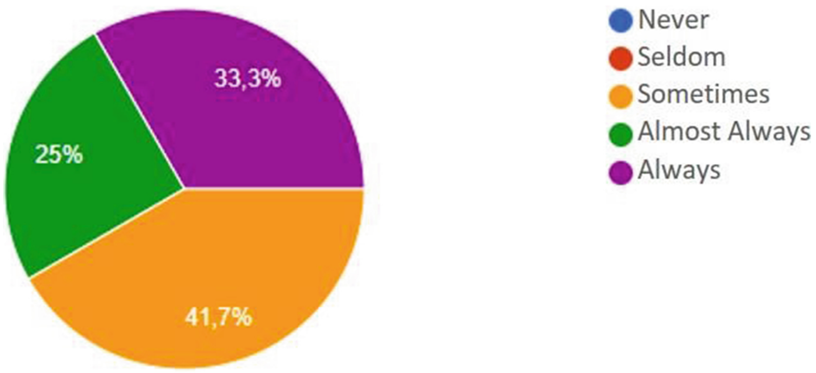

Fig. 12. Answers to the improvement in interpersonal relationships

7. Considers that the Cross methodology used in the conceptual design of the prototype allows to encourage decision making (Fig. 13).

In agreement with what is shown in Fig. 7, the Cross methodology is an excellent means to encourage decision-making. 58.3% considered that they always did, while 41.7% considered that they did it almost always.

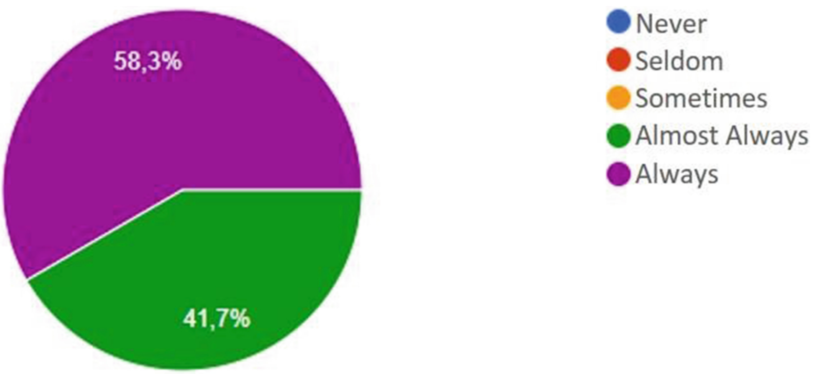

Fig. 13. Responses to the incentive in decision making

4 Conclusion

As a conclusion it can be deduced that the competences that most favor the methodology for designing prototypes in the SICAP research seeding are decision-making and communication with the work group and between colleagues. On the other hand, it is a set of good practices for the management of creativity and innovation, teamwork, the management of the scientific method in the development of projects and the interpersonal relationship between the work team. However, it is necessary to work with some methodological and didactical strategies that support the time management

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