A Process for Solving Ill-Structured Problem Supported by Ontology and Software Tools

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Abstract. Problem solving requires a lot of work for selecting and organizing resources and information, as well as defining the best solution approaches. In the case of ill-structured problems (ISP), due to the possibility of several potential solutions, the task becomes harder. Group work can better support this task but requires cognitive tools in order to allow the registration and the recovery of data about the problem and the exchange of ideas. This paper presents a process to support solving ISP, using ontology and software tools in order to facilitate the group work. Preliminary experiments indicate the feasibility of the process.

Keywords: Ontology, software tools, collaborative work, ill – structured problems.

1 Introduction

Problem solving is one of the most important kinds of higher ordered thinking. To solve a problem it is necessary to understand what the problem is about, the involved concepts in it and how to apply these concepts. Additionally, some relevant questions are the following [19]:

- What is affected by the problem?
- Which partial questions help to solve the problem?
- How to make a characterization or a classification of a problem?
- What are the main elements of a problem?

When a group of people are thinking about a unique problem, more knowledge and better solutions can arise. The group can work in a cooperative or a collaborative way. In a cooperative way, the problem is divided in sub-problems and each sub-group is responsible for solving a part of the problem and at the end the partial solutions are integrated. In a collaborative way, everybody thinks together about the problem and it is necessary to have a consensus about each partial solution involved in the problem.

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Anyway, the work in group requires cognitive tools for registration and recovery of the data about the problem and about the exchange of ideas.

This paper proposes a process to support the solving ISP, by using ontology and software tools in order to facilitate the thinking in group. It is organized as follows. Section 2 presents a literature review. Section 3 describes the suggested process for solving ISP. Section 4 presents a carried out experiment. Finally, Section 5 presents the conclusion.

2 Literature Review

There are many definitions of what a problem is. Some dictionaries say that a problem can be a question to be considered, solved or answered. Others consider a problem as a situation that presents perplexity or difficulty. In the most general sense, a problem is an unknown that results from any situation in which a person seeks to fulfill a need or accomplish a goal. However, problems are problems only when there is a "felt need" that motivates people to search for a solution in order to eliminate discrepancies [1].

According to Garey and Jonhson (1979), a problem is a question to be answered, usually possessing several parameters and free variables whose values are left unspecified. A problem has a description and a statement of what properties the solution must satisfy. In summary a problem has the following characteristics [12,19,24]:

- Problems are problems only when someone is aware of them;
- Problems are problems because they have no easy answers – if they did, they would be already solved;
- Solutions can bring other problems;
- What was a good solution once perhaps does not work anymore.

There are many kinds of problems and classifying them is an important and hard task, a real problem. A variety of criteria like complexity or nature can be used for that. The computational complexity theory deals with the required resources during computation to solve a given problem. The most common considered parameters are the time and the space, indicating how many steps are taken and how much memory is required to solve a problem, respectively [5].

When a problem exists it is necessary to have people with appropriate cognitive skills to solve it. For this, the use of adequate methodology and software tools can facilitate the work.

2.1 Well - Structured Problems (WSP) and Ill - Structured Problems (ISP)

According to Goel (1992), there are interesting differences in the task environments of well-structured and ill-structured problems, leading to some nontrivial differences between ill-structured and well-structured problem spaces. In addition, Goel points out that the distinction is not universally accepted [23]. Anyway, a brief and general notion about the definition of these two kinds of problems is presented next.

Well-structured problems (WSP) are logically coherent and consistent [10]. Their data are easily identified. Generally, this kind of problem is used in training. Areas like Mathematics and Engineering have a large quantity of well-structured problems. To solving a problem of this type, it is required the application of a finite number of concepts, rules, principles, well-defined initial state, a known goal and a constrained set of logical operators.

An ill-structured problem (ISP) emerges from social dilemma or from people quotidian activities [19]. People have very different perceptions and values concerning its nature, its causes, its boundaries and its solutions. There is not a unique solution for it. Each person has a way to solve it. Each people have own idea or opinion about that dilemma.

Lynch et. al (2010) consider an ill-structured problem as an ill-defined problem and say that it is of this kind when essential concepts, relations, or solution criteria are unspecified or underspecified, open-textured, or intractable, requiring a solver to frame or re-characterize it. Lynch et. al emphasize that this re-characterization and the resulting solution are subject to debate.

Some examples of ill-structured problems are the following:

- How to minimize the quantity of cars on the streets?
- How to improve learning in a given group of people?
- What is the best way to teach a person?
- How a postgraduate program can improve its academic productivity?

According to Simon (1986) other examples of ill-structured problems are the majority of corporate strategy problems and governmental policy problems because they are complex problems and sometimes ill defined. Also, the very nature of each problem is successively transformed in the course of exploration.

Hatchuel (2001) argues that during a problem solving process new variables or options can arise as a consequence of human creativity. Besides, depending on problem solvers' feelings, the goals to be accomplished sometimes are ambiguous. For Lynch et al. (2010) just the question of defining ill-defined problems and domains is itself ill-defined.

Anyway, if ill-structured problems exist then it is necessary to try to solve them. That explains why the work of various segments of society is to making decisions and solving problems. According to Simon (1986), the activities of fixing agendas, setting up goals and designing actions are usually called problem solving while evaluating and choosing are usually called decision making. Therefore, a relevant question is how to solve ill-structured problems.

2.2 How to Solve an Ill - Structured Problem (ISP)?

Simon (1986) suggests that the first step in the problem solving process is to comprehend what the problem is about. This way, some relevant questions are the following: What aspects of problem have most priority? And when a problem is identified, how can it be represented in a way that facilitates its solution?

The solution for an ill-structured problem depends on many factors, such as: criteria for evaluating solutions, consensual agreement and personal opinions or beliefs. Ill-structured problems have multiple solutions, a variety of solution paths, and fewer parameters which are less tractable. Problems of this type contain uncertainty about which concepts, rules and principles are necessary for the solution or how they are organized and which solution is the best one on that moment [12]. So, solving an ill-structured problem requires a lot of work for selecting and organizing resources and information, as well as defining solution approaches. After intensive discussions, a group of problem solvers can choose or not the best solution or answer for a specific ill-structured problem at a specific moment.

So, it is necessary to find mechanisms to collect opinions, to register the results of idea exchanging, and to use structured forms for representing consensual opinion of a group. Simon (1986) argues that the problem solving relies on large amounts of information that are stored in memory and that are retrievable whenever the solver recognizes cues signaling its relevance. In addition, he considers that the way in which problems are represented has much to do with the quality of the solutions that are found. In other words, good representation of the problem can lead to good solution.

In order to solve a problem, it is necessary to have methods or algorithms for this. In accordance to Hatchuel (2001), Simon [23,24,25] often insisted that in facing a problem, the natural way is simultaneously to discuss alternatives, goals, constraints and procedures.

Hatchuel (2001) describes a basic procedure of problem solving as the generation of a short list of possible solutions that could be evaluated and compared. Next, he analyzes that a set of solutions related to a specific problem can be infinite or uncountable.

The process of problem solving requires meta-cognition. Hartman (2001b) identifies two types of meta-cognition: strategic knowledge and executive management strategies. Strategic knowledge includes knowing what information, strategies and skills are available; when, why and how to use them. Executive management strategies include activity planning.

Anyway, for the majority of already cited authors, solving ill-structured problem is a work to be done in group, be it in a collaborative or cooperative way.

Johnson and Johnson (2004) also provide hints on how to form a cooperative group. A cooperative group needs to have the following elements: positive interdependence, individual and group accountability, pro-motive interaction, appropriate use of social skills and group processing. Also, they cite that other authors found that students working in groups of two or three seemed more likely to interpret program questions as the authors of the materials intended, indicating that students will learn how to use hardware and software more quickly and effectively when they learn in cooperative groups rather than alone.

For Hatchuel (2001), problem solving is a favorable context for learning.

2.3 Problem-Based Learning (PBL)

Problem-Based Learning (PBL) is a methodology focused on problem solving in order to accomplish its goals. Improving problem solving skills is one of the essential promises of PBL. In this methodology, students work in small groups with the guidance of a facilitator in solving problems and reflecting on their experience [3]. Collaboration allows learners to share ideas, develop authentic solutions for a problem and acquire useful knowledge.

According to Hung et. al. (2008), the PBL process normally involves the following steps:

- Students in groups think about the problem. They attempt to define, bound the problem and set the learning goals by identifying of what they already know, what hypotheses or conjectures they can think of, what they need to learn in order to better understand the dimensions of the problem, what learning activities are required and who will perform them.
- During self-directed study, individually the students complete their learning assignments. They collect and study resources and prepare reports to the group.
- Students share their learning with the group and revisit the problem, generating additional hypotheses and rejecting others based on their learning.
- At the end of the learning period, students summarize and integrate their learning.

Among others, Mencke and Dumke (2007) present an interesting ontology concerning the PBL steps, which consists of six main steps, namely, problem definition phase, research phase, evaluation phase, decision phase, implementation phase and control phase.

According to Trevena (2007), a PBL didactic approach should have seven basic steps, namely: clarify terms and concepts; define the problem; analyze the problem; draw systematic inventory; formulate learning objectives; collect additional information; synthesize and test the new information.

Though useful steps of PBL are already known, implementing them is not a trivial task because one of its goals is to improve problem solving skills. For that it is necessary to stimulate the meta-cognition on the students. Hartman (2001a) advises that sometimes the improvement of the students on this aspect is hard to be observed.

According to Jonassen (1997), a process of ill-structured problem solving should contain the following steps: group of people articulate the problem space and contextual constraints; identify and clarify alternative opinions, positions, and perspectives of stakeholders; generate possible solutions for the ill-structured problem; assess the viability of alternative solutions by constructing arguments and articulating personal beliefs; monitor the space of problem and alternative solutions to anticipate the possible outcomes from the selected solution in order to prevent disasters or inconveniences; implement and monitor the solution; adapt the solution.

Comparing the steps concerning the PBL and the steps related to the process of ill-structured problem solving, it can be noted that they have several similarities.

2.4 Some Support Software Tools for Solving ISP

Work in group can better support the process of problem solving but requires cognitive tools in order to allow the registration and the recovery of the data about the problem, and the exchange of ideas. Soller et. al (2005) describe the phases of the process of collaboration management: collect interaction data, construct a model of interaction, compare the current state of interaction to the desired state, advise or guide the interaction, evaluate interaction assessment and diagnosis. It is crucial that everyone in the group understand and registry the relevant information. Also, the information recovery should be accessible to the whole group to allow sharing of ideas.

Soller et.al (2005) analyzed a variety of system that support collaboration but those systems are not complete in terms of collaboration management. This way, some software tools to support collaboration (Protégé, Compendium and NeON ToolKit) are presented next.

Protégé is an ontology editor and has a variety of graph based visualization plug-ins that facilitates its use. According to Lanzenberger et. al. (2010), visualization has a potential appeal to creation, exploration and verification of complex and large collections of data. The simple creation process of an ontology leads to reasoning about a problem.

Pérez and Benjamins (1999) already indicated ontologies and problem solving methods as promising candidates for reuse in Knowledge Engineering, citing both as complementary entities that can be used to configure new knowledge systems from existing, reusable components. Additionally, the last cited authors give from the literature many definitions about what an ontology is. In this work, an ontology is considered as a set of basic concepts and the relations between them, combining rules. For example, on the sentence *problem has data,* the words *problem* and *data* are concepts, *has* is a relation between *problem* and *data*. An implicit rule should be that a problem has at least one data. Concepts and classes are considered synonymous on ontology like relation and property. An ontology can describe a specific domain, a specific situation or a problem. A meta-ontology is a generic ontology that can be instantiated to several domains.

Another ontology editor is the NeON toolkit that is an ontology engineering environment for modeling ontologies. It is based on Eclipse and a modular design that is extensible by plug-ins contributed by external developers [18]. Protégé 4.0 and NeON ToolKit 2.3.2 have complementary characteristics.

The Issue Based Information Systems (IBIS) represents argumentation using issues, positions, and arguments [2]. Horst Rittel [2] has developed the IBIS methodology, which is based on the principle that the design process for complex problems, like ISP, is fundamentally a conversation among the stakeholders in which they bring their respective expertise and viewpoints to the solution of design issues. Any problem, concern or question can be an issue and may require discussion. Issues are the design problems to be discussed by the team members. Positions are possible ways of addressing an issue. Arguments support the positions. Issues, positions and arguments are represented as nodes in IBIS diagrams. In order to complement the representation of the argumentation, nodes can be connected by any of the following eight link types: supports, objects-to, replaces, responds-to, generalize, specializes, questions, and suggested-by.

The IBIS methodology can help the process of problem solving but it is important to have computational tools that support and promote a good visualization about what is going on. Jung (2008) advocates that semantic heterogeneity should be dealt with the support to the process of sharing automated information among the information systems in distributed environments but recognizes the difficulty to obtain ontology mappings between all possible pairs of the information systems. Okada (2008) sees mapping software as a set of visual tools and figures out that maps of concepts, discussions and arguments make the connections between tangible and disputable ideas.

For Okada (2007), Compendium software can be very useful for organizing knowledge in several contexts: conceptual studies, problem solving, literature review, learning path planning, argumentative discussions and learning design. She also sees that Compendium maps can offer several benefits like: to allow students to recognize their way to represent their thoughts; encourage participants to make interventions and improve their productions, building knowledge collectively, easy and practical way to seek relevant information, cooperative learning, closer engagement in problem with peers, answering and generating questions to understand various aspects of the investigation. Besides that, Compendium makes possible to work with IBIS methodology.

3 Proposal of a Process for Solving ISP

Based on Jonassen (1997), Trevena (2007), Hung et. al. (2008), Mencke Dumke (2007) and Simon (1986), a process for solving ill-structured problem was defined. This process is supported by ontology and software tools. Fig. 1 shows each step of this process.

3.1 Contextualization of a Critical Situation

In the most general sense, any situation is a problem when there is a necessity that motivates people to search for a solution in order to eliminate perplexity or difficulty. In other words, people have to be aware about the problem and to feel that the situation is a problem or it is uncomfortable. So, it is very important to show video, photos, a variety of materials that lead the group to identify the ill–structured problem. It is necessary to create empathy between the people and the situation. The facilitator just presents the situation and asks people to identify what the problem is. The facilitator should not stimulate any feeling about the situation.

3.2 Definition of the Problem

The group decides if the problem really exists and tries to understand what the problem is. Though group work can produce better results than individual one, obtaining consensus among participant‘s opinions is not an easy task.

In order to facilitate this step, a questionnaire survey and an online discussion forum can be used, identifying the space and contextual constraints of the ISP. All information should be registered on a file and left available to everybody. The constraints, issue, questions, characteristics of problem are going to be used to build the ontology for the ISP.

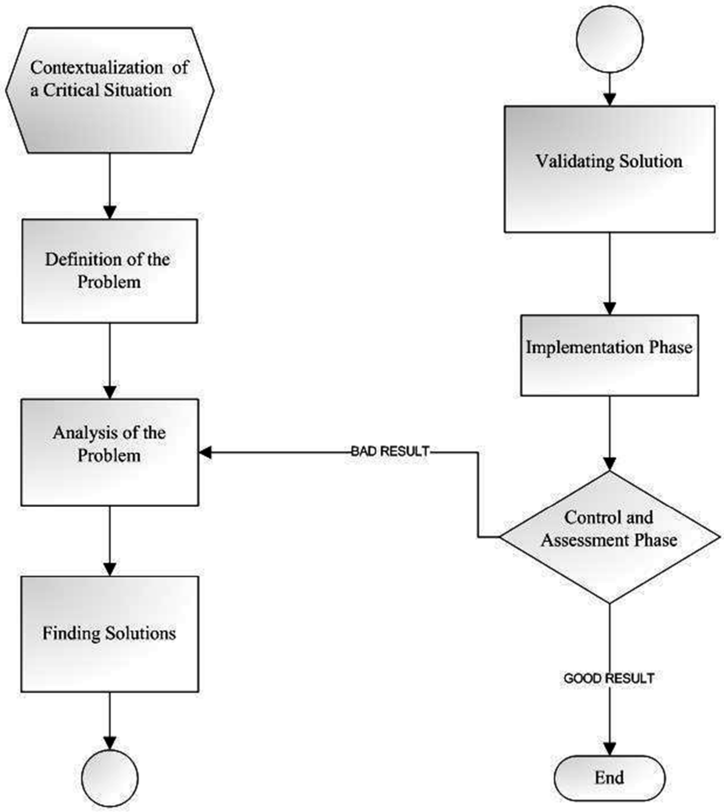

Fig. 1. Steps of the Process for Solving ISP

3.3 Analysis of the Problem

An ISP can encompass various questions. The frontier between the well-structured problems and the ill-structured problems is very fragile what makes the classification of a problem a hard task. It is necessary to know the variables and the context in which the problem is inserted. The understanding and the adequate representing of a problem facilitate its solution.

In this paper a meta-ontology is proposed as a way to describe the classification of any problem. The meta-ontology tries to explain how a problem can be classified to show the main elements of a problem and to help people understand the dynamism of any problem. For example, when a group does not know how to start analyzing the problem, the meta-ontology shows that any problem has facts and the description contains relevant data. In addition, the meta-ontology helps people build a synthesis of the problem.

This meta-ontology is a consequence of the last studies of the authors, joining literature review, oriented thesis and survey with workers, the called problem-solvers, in companies.

So, after the identification of the main components of a problem and grouping them into classes, each couple of problem-solvers should build an ontology about the ISP, based on the meta-ontology presented in Fig. 2. Each couple of problem - solvers can relate their point of view about the problem, add new perspectives and share previous knowledge or beliefs about the ISP.

So, the merge of the each built ontology occurs. Then, there will be a single ontology for an ISP in each group. This phase has the goal of ensuring that all group understood what the ISP is and the questions related to it.

It is important to remember that a concept map is quite similar to an ontology. Both ontology and concept map represent some domain. Both have classes or concepts and relations between them. Unlike concept maps, ontology has also attributes for classes, their values and restrictions on them.

When the language OWL is used on the building of an ontology, at least it is possible to distinguish two kinds of restrictions: value constraints and cardinality constraints.

A value constraint puts constraints on the range of the property when applied to this particular class description. Related to the meta-ontology presented in Fig. 2, the following code shows an example of the use of value constraint.

```
<owl:Class rdf:about="&ontology1;Problem">
    <owl:equivalentClass>
      <owl:Restriction>
        <owl:onProperty rdf:resource="&ontology1;belongs_to"/>
        <owl:someValuesFrom rdf:resource="&ontology1;Categorization"/>
      </owl:Restriction>
    </owl:equivalentClass>
```

The last code indicates that *Problem* (class) *belongs_to* (property) *Categorization* (class). The value constraint *someValuesFrom* restricts the range of property *belongs_to* to instances of the class *Categorization*.

A cardinality constraint puts constraints on the number of values a property can take, in the context of this particular class description. Related to the meta-ontology presented in Fig. 2, the following code shows an example of the use of cardinality constraint.

```
<owl:Restriction>
        <owl:onProperty rdf:resource="&ontology1;posses"/>
        <owl:onClass rdf:resource="&ontology1;Fact"/>
            <owl:minQualifiedCardinality
                rdf:datatype="&xsd;nonNegativeInteger">1
            </owl:minQualifiedCardinality>
</owl:Restriction>
```

The last code tells that the property *posses* has as range at least one instance of the class *Fact.* The cardinality constraint *minQualifiedCardinality* tries to guarantee that.

Fig. 2. Meta-ontology for a problem

3.4 Finding Solutions

As already mentioned, an ISP is composed of various questions. If it is possible to find a satisfactory answer for each question related to ISP, the general solution is found. Then, the goal of this phase is to generate possible solutions for an ISP. The identification of the solution for a problem can mean eliminating causes or minimizing effects. So, in this paper, it is considered that a valid answer to a question represents a partial solution for the whole problem. This way, each couple of problem-solvers should find partial solutions for the ISP, with solid arguments for each idea.

This phase can be supported by the use of argument maps of the IBIS methodology. With the use of maps, each couple of problem-solvers can just answer a subset of questions. At the end and in the case of cooperative work, the maps are integrated. In the case of collaborative work, the couples try to answer every question and afterward the best answers are selected.

3.5 Validating Solution

An ISP has multiple solutions but not all of them are necessarily viable. Some solutions are absurd, others are very expensive and others can generate other ISP, maybe greater than the original one. This way, it is necessary to analyze the potential solutions. Each couple of problem-solvers shows their argument maps, with the arguments pros and cons, according to their own mind, experience and beliefs. In this process it is important the participants be aware that respecting and accepting the other opinions is crucial. So, the knowledge modeling can support the analysis of alternative solutions and finding the best one by the group at that moment. The result of this phase is a unique argument map indicating the best partial solutions.

3.6 Implementation Phase

Many problems are so complex and inaccessible that a recommended solution cannot be tried out, so it is sufficient merely to articulate the possible solutions. But if the solution or the partial solution is implementable, now is the moment. However, it is necessary to monitor how this solution is affecting all variables of the problem.

3.7 Control and Assessment Phase

This phase identify if the partial solutions need adjustments before being considered the best one. Only after this work, it is possible to identify details or situations that have not been thought of before. If the best solution for an ISP is found in that community, maybe this solution can be applied to other contexts, with similar problem.

4 Case Study

In this section an experiment made with 40 learners of a undergraduate course in Informatics on FATEC (Technology Faculty), within 20 to 45 years old, is presented. The learners were divided in two groups and have been worked in pairs. The interval between each phase was fifteen days, approximately. The experiment contemplated until the step 4 of the process for solving an ISP.

4.1 Contextualization of a Critical Situation

The social inequality in Brazil is an actual subject highlighted in the newspapers, almost every day. There is a variety of videos, photos, papers and reports related to it.

So, a video reporting about social inequality in Brazil produced by a local newspaper (www.g1.com.br/jn) was shown to learners.

4.2 Definition of the Problem

After watching the video, the group of learners identified that the social inequality in Brazil is a problem. So, they tried to understand the space and contextual constraints of the problem. Each pair filled out a questionnaire survey and posted it with the support of *Moodle* tool at http://www.fatecsjc.edu.br/fatec-ead/. A unique list with concepts, questions and issue was consolidated and all groups have access to it.

4.3 Analysis of the Problem

Each pair built an ontology about the problem, based on the list created on the last step, and salved it on file. Here, each pair used the Protégé 4.0.2 for that.

When each pair finished its particular ontology, the group had a meeting in order to debate and to merge all built ontologies, creating a new one. All ontology had some similar concepts and others too different. The differences enrich the final ontology. The Protégé was used to merge and some inconveniences occurred, such as: duplicity of concepts on the final ontology due a letter added; the merging of ontologies requires patience because it must be careful and it involves interaction, argumentation and tolerance among the problem-solvers. The Neon-ToolKit was used to produce the graphs and some relations had to be done again. A part of the final ontology is presented in Fig. 3.

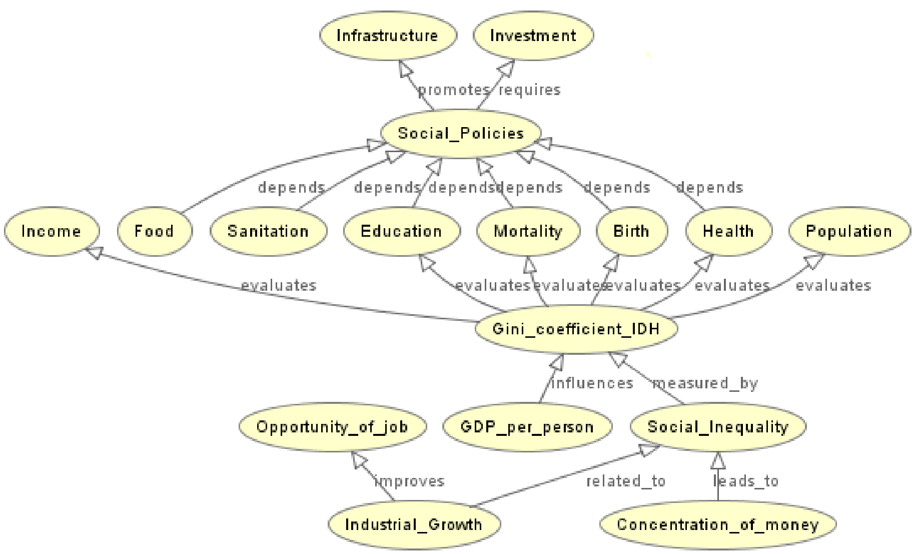

Fig. 3. A part of the final ontology

4.4 Finding Solutions

Fig. 4 presents an excerpt of the built argument map related to social inequality. That figure was built using Compendium.

Compendium supports IBIS (Issue-Based Information System) methodology and makes possible to build argument maps. “The social inequality in Brazil” was considered an ISP by learners. These ISP is composed of various questions. Each pair has been tried to solve each question or issue, expressing arguments in favor of or against it.

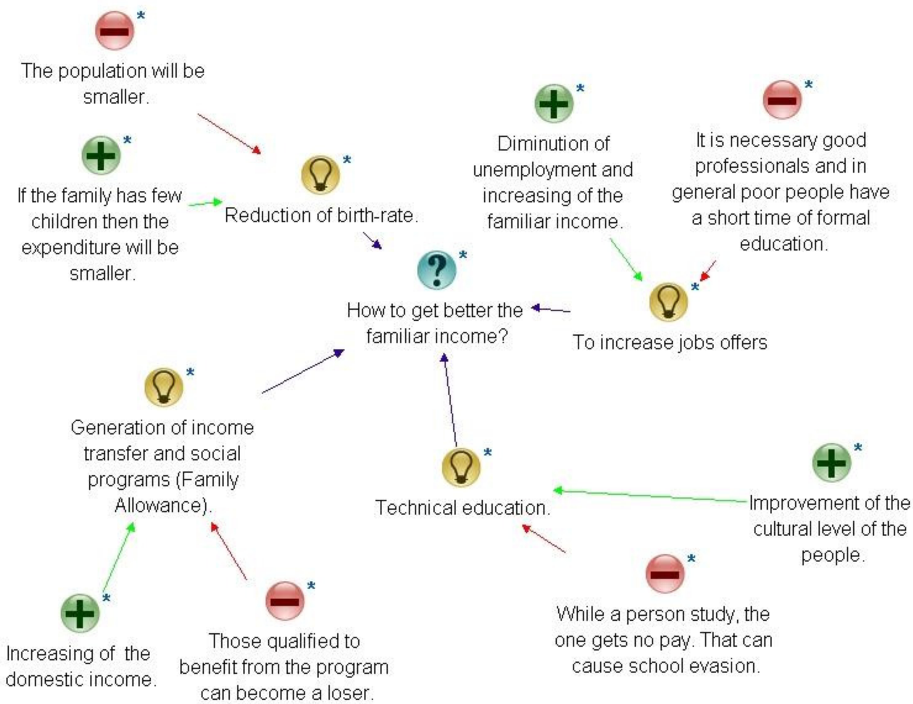

Fig. 4. An excerpt of the argumentation map

5 Conclusion

This paper presented a process for solving ISP using computational tools and ontology. During the process a meta-ontology for description of problems was used in order to support learners. It shows a variety of kinds of problems and their characteristics, how a problem can be classified with their main elements. The meta-ontology can help people understand the dynamism of any problem, showing a way for analysis.

The use of the ontology can help learners better understand a problem. The ontology is not a popular discipline in undergraduate education and this work helps to divulge it. The analysis of problem is too important. Another outcome of this work is that the learners perceived that it is necessary to understand what the problem is, thinking about that and after to try solve it. So, the learners do not solve the problem of Social Inequality, but they analyzed and understood the problem during the process of building the ontology. Besides, they noted that Social Inequality is a problem but the Social Equality also should be a problem. The use of ontology was essential in order to help students to organize and understand each concept related to Social Inequality in Brazil.

The cooperative work is easier to implement than collaborative work. The last one required much more discussion, tolerance and punctuality than the first one. Also, the variety of vocabulary was greater in the collaborative work, generating richness and divergences. The diversity is richness and needs to be treated adequately. The simple merge of ontology does not guarantee that the diversity of vocabulary will be preserved. Another point is that one ontology, for instance, made by experts and other made by researchers cannot have the same value. Maybe the use of multifaceted ontology can bring some new insights on this aspect.

Future work should be based on the obtained results. The steps 5, 6 and 7 of the process will be tested, yet. As future work, it is desirable a unique argument map indicating the best partial solutions and a way to test them.

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