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An Ontological Approach to Support Teachers in Designing Instruction Using ICT

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Abstract: In this study, we have developed a system called FIMA (Flexible Instructional Design Support Multi-Agent System) which supports teachers dynamically in designing instruction by facilitating their thinking in ways characteristic of expert teachers' thought processes: 1) multiple viewpoints thinking, 2) contextualized thinking and 3) problem framing and reframing strategy. We especially focus on instructional design that integrates the use of information and communication technology (ICT). In this paper, we describe one function of FIMA: to evaluate ICT-use instruction designed by teachers and support them according to results of the evaluation.

Keywords: Ontology, Instructional Design, Multi-Agent, ICT Use in Instruction

Introduction

The educational gaps caused by differences in teachers' professional abilities are a perennial problem. Among several approaches to this problem, providing them with an efficient and usable support system is promising, since most teachers want to participate in the process of designing high quality instruction. In order to investigate strategies to support less-skilled teachers in designing instruction, it is best to analyze skilled teacher's thinking processes in approaching this task. Sato et al. investigated differences in thinking processes between expert teachers and novice teachers when they analyzed others' instructional plans [1]. This investigation came to the conclusion that the thinking of expert teachers is characterized by the following three features: 1) multiple viewpoints thinking, 2) contextualized thinking, and 3) problem framing and reframing strategy. Because it is also important for teachers to analyze instruction objectively when they themselves design instruction, this study aims to support teachers in designing high quality instruction through facilitating these three factors of thinking.

By "multiple viewpoints thinking", Sato means that expert teachers conceptualize instructional propositions and learning propositions in a mutually dependent way. To facilitate teachers' multiple viewpoints thinking, it is important to make them conscious of the relations between various concepts concerning both instruction and learning when they design instruction as well as effective to provide support information together with related concepts according to teacher's needs. By "contextualized thinking", he means that expert teachers think of a lesson part not independently but in the context of other lesson parts which occur before and after it during an instruction. To facilitate such contextualized thinking, it is important to make him/her conscious of the flow of instructional and learning activities for achievement of educational goals; indeed, many teachers want such support to help them confirm whether or not the flow of instructional and learning activities they have designed achieves a given educational goal. By "problem framing and reframing strategy", he means that expert teachers are so flexible that they can easily adapt to the situation without persisting in the pre-set plan and their thoughts. By contrast, the instructional design process conducted by most teachers which sometimes include expert teachers is a waterfall type process like the instructional design process model by Gagne [4] which is still typical among the models presented to date. So, it is important to facilitate teachers' "problem framing and reframing strategy" when they design instruction. To facilitate this thinking, it is effective to control teacher's instructional design process flexibly; for example, to stimulate teacher to reconsider educational goals according to the progress of the instructional design process.

These three factors of thinking become more serious in the case of instructional planning using ICT. For example, it becomes difficult for even expert teachers to think from multiple and contextual viewpoints keeping concentration on information systems and digital materials with which they are not fully accustomed. In order to enhance practical abilities like IT education, reconsideration of educational goals of instructions during the design process would be effective, since required abilities for students might change according to the detailed situation given to them. Concerning the computerization of school education, teachers want such supports that allow them suitably implement IT education and ICT-use instruction. Furthermore, in order to support teachers who implement IT education, it is important for them to try to clarify the concepts of educational goals which it is difficult for them to understand exactly as a basis of various supports, and, in order to help teachers implement ICT use, it would be good to help them clarify what purpose they use ICT and why they use ICT in instruction. After these kinds of support, we would be able to facilitate teachers' above three kinds of thinking skills.

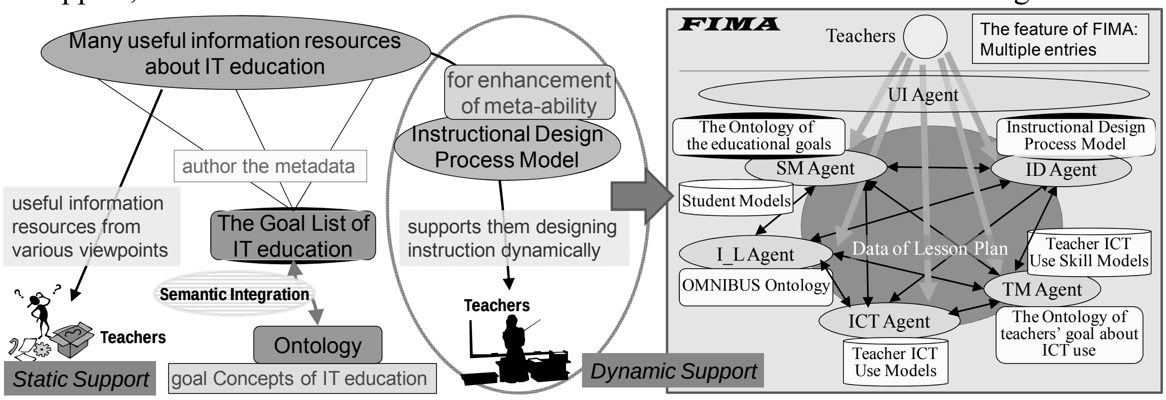

Figure 1. The whole outline for the teacher support to design instruction

Through these considerations, this study investigates a support system for teachers in designing instructional plans by two frameworks. One is a framework that provides teachers with various pieces of useful information together with other related information based on the concepts of educational goals as shown on the left in Figure 1. This framework has been already realized and gets certain results by building the ontology of the goal of IT education [2][3]. The other is a framework that supports teachers dynamically in designing instruction. Supporting teachers by facilitating teacher's three thinking skills not independently but all together must be done dynamically in designing instruction, because modification of part of an instruction would require reconsideration of the whole instruction by "the multiple viewpoints thinking" and "the contextualized thinking". In order to realize such support, we have proposed a Flexible Instructional design support Multi-Agent system, called FIMA which is based on multi-agent architecture in consideration of the support's principle which the system supports teachers dynamically in designing instruction from multiple and contextual viewpoints (in this paper, we call this support "dynamic support"). We have discussed the structure of FIMA and its necessity [5]. FIMA is composed of six agents as shown on the right in Figure 1. In FIMA, each agent has a function that can support teachers from each viewpoint that teachers should consider in the instructional design process. All agents can be the first functional module fired by the first action taken by a teacher as the user. For example, when a teacher asks FIMA for support for instructional design in which he/she makes use of ICT and it can execute on a premise of his/her ability of ICT use, the TM (Teacher Model) Agent which is one of the agents in FIMA and has the function of supporting teachers from the viewpoint of the teacher's ability of ICT use becomes the entrance of the system and supports him/her. The agent which becomes the entrance of the system requests information from the other agents' viewpoints if necessary, and provides teachers with support information through the integration of the gathered information. The characteristics of FIMA are as follows:

- Basic Principles include:
    - Not to design instruction automatically, but to support teachers dynamically in designing instruction by themselves
    - To facilitate teachers' multiple viewpoints and contextualized thinking
    - To facilitate a flexible instructional design process
    - To provide teachers with support information according to their situation
- Support for the computerization of school education
    - To provide teachers with support information based on the ontology of the goals of IT education
    - To facilitate teachers' ICT use through making them specify purposes of its use and why do they use ICT
- Support to confirm suitability of "the contextualized thinking"
    - To evaluate flow of instructional and learning activities based on instructional/learning theories and to support teachers according to the results

We have realized the support to provide teachers with support information based on the ontology of the goal of IT education [2][3]. In this paper, we describe the last two points in detail completing our discussion of the above characteristics. To be concrete, first, we focus on the use of digital materials which is typical and fundamental in ICT use, and then we argue for a strategy that evaluates instruction which using digital materials and supports teachers who design such instruction according to the results of the evaluation. It means that we discuss mainly the function which is performed by the ICT Agent and the I_L (Instruction and Learning) Agent in FIMA. Every function invokes an interaction between all agents to support teachers from the multiple viewpoints. However, in this paper, to avoid the dispersion of the discussion, we describe the function which is performed only by the ICT Agent and the I_L Agent. Further, we do not directly describe how teachers are dynamically supported in designing instruction, but instead, we describe how FIMA evaluates teacher-made instruction plans from the multiple viewpoints and the contextualized viewpoint and how it supports them to refine the plans based on the results.

1. The Support for the Use of Digital Materials

1.1 The Metadata of Digital Materials

It is important to objectively evaluate whether digital materials are suitably used in instruction. Teachers are required to be conscious of important viewpoints (contents and features of digital materials, reasons of their use, educational goals in their use scenes, and so on) in use of digital materials in instruction from the multiple viewpoints and the contextualized viewpoint so that teachers themselves can judge whether digital materials are made use of suitably. In this section, we describe the support (a function by the ICT Agent) to make teachers conscious of these viewpoints only from the multiple viewpoints, because the support from the contextual viewpoint is the same as the support described in section 2.

To make teachers conscious of contents and features of digital materials, it is effective to specify this information as their metadata. So, in this study, we describe a set of two items: “target object” and “expression way”, which show contents and features of each digital material as metadata. Then, more than one set of the two items for every digital material can be described in metadata, because the “target object” varies according to the context in which the digital material is used.

Every concept can become value of “target object”. However, because every digital material we discuss in this paper has been created to be used in school education, its contents should be related to educational contents of school education. So, in this study, we systematize the concepts of educational goals of every subject contained in elementary and secondary education as an ontology, and add at least one concept defined in the ontology as a “target object” into the metadata of every digital material. Next, as “expression way”, we prepare eleven values: “slow-speed image”, “animation”, and so on, with the aim of expressing features of digital materials. Thanks to the metadata, teachers can not only search necessary digital materials efficiently, but also be clearly conscious of the contents and the features of digital materials when they make use of them.

Here, we discuss the scalability of this metadata. Because it is difficult to author this metadata which includes essential detailed information related to the contents of digital materials, the scalability is important issue. To solve this issue, in this study, we have a plan to organize a study group which aims to develop digital materials and to author their metadata, though it is limited to the area which the first author of this paper works in. At present (May 2009), we already have about 500 digital materials annotated with metadata.

1.2 What teachers specify in instructional design process

Letting people describe various related concepts together would facilitate their multiple viewpoints thinking, FIMA facilitates teachers’ multiple viewpoints thinking, by making them describe a set of instructional and learning activities together with educational goals (by selection from the concepts defined in the ontology of educational goals), unit of the learning activity (individual/group/class), type of the instructional activity, type of the learning activity, digital materials, “target object” and “expression way” of digital materials, and reason to make use of ICT. Then, FIMA can analyze the relation between the educational goals and “target object” of digital materials based on concept structure defined in the ontology of educational goals, because these are selected based on this same ontology. If contradiction is extracted by this analysis, FIMA can request teachers to confirm it. The value which teachers can select as the type of instructional and learning activity has also a role as a key to translate automatically to concepts which are defined in the OMNIBUS ontology described in the next section. So, in this study, we prepare 58 concepts of activities which teachers can feel a sense of closeness and describe the relation with the 99 concepts of learning and instructional activities which are defined in the OMNIBUS ontology. For example, a concept “Solve a problem” (one of learning activities) which FIMA prepares can be translated to concepts: “Perform” and “Solve” which are defined in the OMNIBUS ontology. As the reason to make use of ICT, teachers select through comparing with another case which they do not make use of digital materials in. Concretely, teachers select benefit of digital materials and a viewpoint which they pay attention to when they decide use of the digital materials (for example, a teacher can select "reality UP" as benefit and "expression" as a viewpoint). By making teachers select these values, FIMA can make them reflect the process to decide to make use of digital materials.

2. The Support from the Contextual Viewpoint

The support (a function of the I_L Agent) to confirm suitability of teachers' contextualized thinking has two methods. One is a method which makes teachers reconfirm suitability of instruction from the contextual viewpoint, by showing the flow of instructional and learning activities for every educational goal. Then, for instruction which includes use of digital materials, FIMA can extract problems by analyzing relation between metadata of the digital materials and other related concepts from the contextual viewpoint and present it to teachers. We explain a concrete example of this method of support in section 3. The other is a method which applies instructional/learning theories which are relevant to the flow of instructional and learning activities to achieve educational goal and supports teachers to refine the activities based on such theories. To search instructional/learning theories which are relevant to instructions which teachers design, we use the OMNIBUS ontology which describes theories in a common form using shared concepts. In order to realize the goal, we need to devise an algorithm for evaluating relevance between each instructional/learning theory in OMNIBUS and instructions which teachers design.

In this section, we describe this method of the support in detail. Here, we explain briefly the OMNIBUS ontology of learning and instructional theories. In the OMNIBUS ontology, instructional/learning processes are modeled from the following two viewpoints: "what" to achieve and "how" to achieve. In this model, "I_L" stands for the relationship between the Instruction and the Learning, and an I_L event is composed of state change of a learner and actions of the learner and the instructor related to the change. And, in the OMNIBUS ontology, "WAY-knowledge" describes how the change of the state aimed by instructional/learning activity (macro) can be achieved by the sequence of change of the states of smaller grain-size (micro) based on instructional/learning theories.

2.1 The Method to Extract Relevant Instructional/Learning Theories

The I_L Agent first tries to find relevant instructional/learning theories based on the flow of instructional and learning activities to achieve educational goal in the following steps. I_L Agent

1. translates every instructional and learning activity into concepts defined in the OMNIBUS ontology based on the description of the relation described in 1.2,
2. extracts concepts defined in the OMNIBUS ontology which the last learning activity in instruction is translated into,
3. extracts a set of "WAY-knowledge" which includes at least one concept extracted in step 2,
4. extracts a "WAY-knowledge" which includes the most frequently appearing concepts which every learning activity in the flow of instructional and learning activities in instruction is translated into. For example, it can consider "WAY-knowledge 1" is relevant to "WAY-knowledge 2", if macro instructional/learning activity which "WAY-knowledge 1" has is same as one of micro instructional/learning activities which "WAY-knowledge 2" has, and
5. decides all the "WAY-knowledge" which are extracted in the step 4 as relevant theories.

2.2 The Method of the Support Based on Relevant Instructional/Learning Theories

When instructional/learning theories which are relevant to the flow of instructions designed by teachers are found, I_L Agent can explain these instructional/learning theories to them. Based on the explanation of these theories, teachers themselves can confirm suitability of the instruction and try to improve it. Then, the I_L Agent can support based on the difference between the flow of the instructions and the relevant instructional/learning theories according to teachers' requests. For example, if there are learning activities only in the relevant theories, the I_L Agent can lightly suggest to teachers adding the learning activities into the instructions.

Next, we describe the support for instruction which includes use of digital materials. This function is realized through interaction between the ICT Agent and the I_L Agent. This support is based on our interpretation that teachers regard instructional and learning activities in which digital materials are made use of as important. For example, if the relevant theories include none of the concepts which are translated from learning activity in which digital materials are used, FIMA can suggest to teachers re-confirming the suitability of the instructional and learning activities in which digital materials are made use of from the contextual viewpoint.

3. The Support from the Contextual Viewpoint

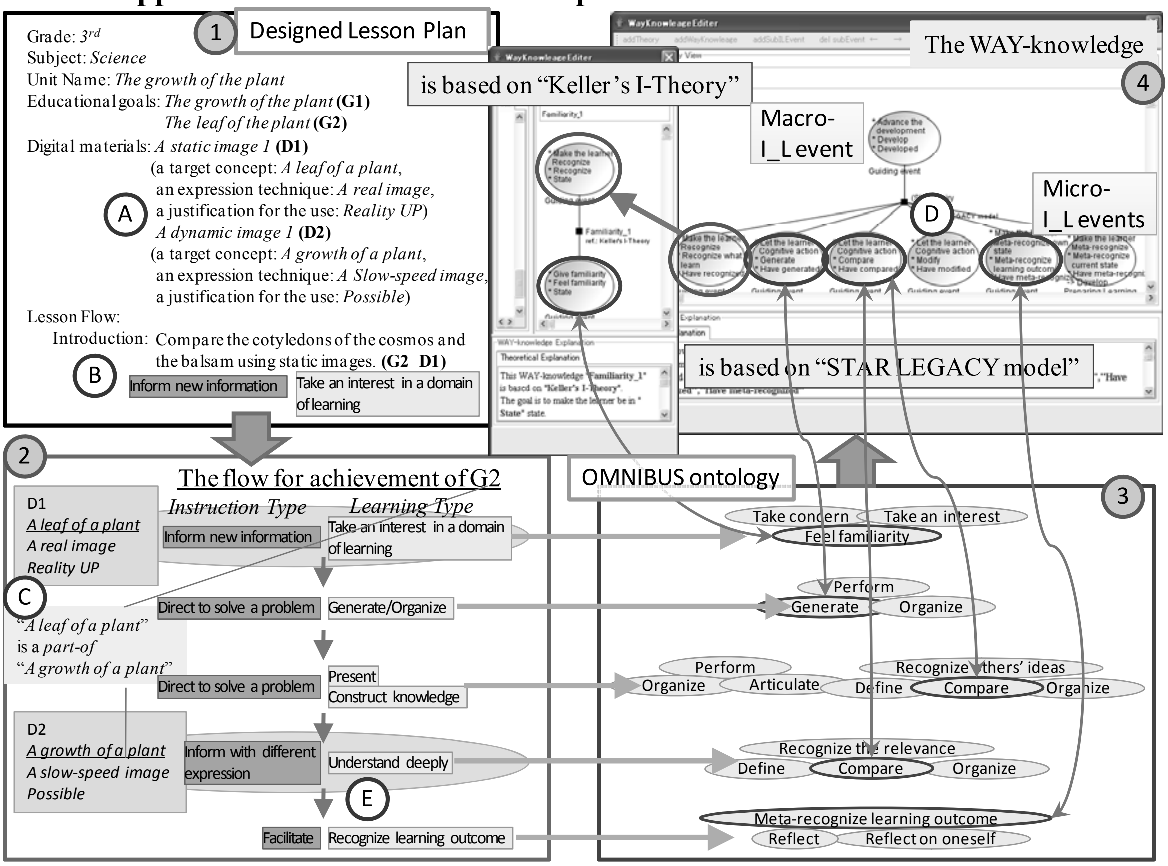

Figure 2. The flow of the concrete support for teachers in ICT-use instruction

In this section, we show an example of the support based on the strategy which is described in section 1 and 2 for teachers in an instruction as shown at ① in Figure 2. In designing instruction using FIMA, teachers select "target object", "expression way", and "reason to make use of ICT" according to the context in which they make use of every digital material as shown at Ⓐ. By making teachers select these values, they can be clearly conscious of important points in use of digital materials in instruction. And, when teachers describe instructional and learning activities, FIMA can facilitate their "multiple viewpoints thinking" by making them select the values of types of the instructional and learning activities, educational goals, and digital materials together as shown at Ⓑ. Next, to facilitate teachers' contextualized thinking, FIMA shows the flow of instructional and learning activities which are designed to achieve each educational goal as shown at ②. In this flow, FIMA can find a doubt about the use of digital materials from the contextual viewpoint by analyzing related concepts based on concept structure defined in the ontology of educational goal as shown at Ⓒ, though there is no contradiction from the multiple viewpoints. This doubt is caused by the situation that a concept of educational goal is a *part-of* "target object" of a digital material used in later part. Because this situation may cause diffusion of students' consciousness, FIMA can make teachers confirm about this doubt. Next, FIMA translates every type of learning activities selected in instructional design into concepts defined in the OMNIBUS ontology as shown at ③. And, FIMA extracts relevant instructional/learning theories in the method described in 2.2. In this example, two theories, "STAR LEGACY model" and "Keller's I-Theory", are extracted as shown at ④. Based on this result, FIMA can support teachers with the following:

- Explaining these theories to teachers.
- Suggesting lightly that teachers add the learning activity "Modify" as shown at Ⓓ which exists only in the theories into the instruction (at Ⓔ in Figure 2).

Thanks to these supports, teachers can confirm the suitability of the instruction which they themselves design and improve the instruction based on instructional/learning theories.

4. Related Work

We would like to briefly introduce some of the other projects related to our approach. [7] has built three ontologies: LOCO is based on IMS-LD, ALOCoM is for learning objects, and LOCO-Cite is for the learning object contextual model. This project intends to extend some of the present Learning Design Editor with the features for searching LO repositories based on the ALOCoM as well as for connecting learning design to LO content components based on the LOCO-Cite. And, many multi-agent systems have been developed for various purposes, because consideration from the various viewpoints is important in the field of Education [8][9]. For example, [8] has developed a novel use of agent technology using autonomous agents to address the key functions of intelligent tutoring systems, which uses learning style schemes to adapts to students individual needs, and which supports the use of learning objects. The incorporation of agents and learning objects is based on learning style a pedagogic foundation for adaptivity. However, to the best of our knowledge, there is no system which can support teachers in designing instruction dynamically regardless of if it is based on multi-agent architecture or not. We believe that one of the causes of this is that most of typical instructional design process models were implemented inflexibly. So, the characteristic of our study is to propose FIMA which can support teachers dynamically in more flexible instructional design process based on multi-agent architecture.

5. Summary

Through the consideration of the thinking of expert teachers, this study aims to support teachers in designing high quality instruction through facilitating the three factors of thinking: 1) multiple viewpoints thinking, 2) contextualized thinking, and 3) problem framing and reframing strategy. For the support, we have proposed two frameworks. One is a framework that provides teachers with various pieces of useful information together with other related information based on the concepts of educational goals. This support is mainly based on outstanding practical cases conducted by expert teachers. The other is a framework that supports teachers dynamically in designing instruction. For this support, we have proposed the FIMA which is based on multi-agent architecture in consideration of these support's principles. In this paper, we discussed the strategy for evaluation of instructions which teachers design and which include use of digital materials and for supporting them using FIMA based on relevant learning/instructional theories. Thanks to these frameworks, it becomes possible for teachers to receive support from both the practical case base and the theory base in designing instruction according to their situation.

Here we explain the current state of implementation of FIMA. At present (May 2009), we have finished implementing private functions of all Agents shown in Figure 1. However, we have not completed to describe enough data which is necessary for each Agent. And, we have not completed to implement the function which integrates the gathered information from multiple agents by interactions between them. So, in this paper, we have described not the interaction between agents but the functions of the I_L Agent and the ICT Agent which have been already implemented. We intend to complete the implementation of FIMA by augmenting the metadata described in section 1 and building the ontology of educational goal in this year. Furthermore, in the next year, we intend to deploy FIMA into the practice of designing instruction by incumbent teachers to investigate the effectiveness of FIMA.

The project of this study is being performed in cooperation with Board of Education and incumbent teachers in Okayama Prefecture, Japan which the first author of this paper works at. This project aims to deploy the results of this study. Concretely, to solve the scalability problem of metadata described in section 1, we have a plan to organize a study group which includes incumbent teachers and which aims to develop digital materials and author their metadata in cooperation with the Board of Education. And, the principles of the support in this study have been decided through discussion with incumbent teachers. Through this cooperation, we believe we can deploy FIMA by overcoming the scalability problem and completing the ontology building of educational goal in this year.

References

[1] Sato M., Iwakawa N., & Akita K. (1991). Pratical Thinking Styles of Teachers: Comparing Experts' Monitoring Processes with Novices, *Bulletin of the Faculty of Education, University of Tokyo, 30*, 177-198.

[2] Kasai T., Yamaguchi H., Nagano K., & Mizoguchi R. (2006). Building an ontology of IT education goals, *International Journal of Counting Engineering Education and Lifelong Learning*, *16*(1/2), 1-17.

[3] Kasai T., Yamaguchi H., Nagano K., & Mizoguchi R. (2007). A Semantic Web System for Supporting Teachers Using Ontology Alignment, *International Journal of Metadata, Semantics and Ontologies*, *2*(1), 35-44.

[4] Gagne, R.M. & Briggs, L.J. (1974). Principles of Instructional Design, *Holt, Rinehart and Winston*, New York.

[5] Kasai T., Nagano K., & Mizoguchi R. (2008). Multi-Entry System for Supporting Teachers in Designing Instruction, *Proceedings of ICCE2008*, 79-86.

[6] Mizoguchi, R., Hayashi, Y., & Bourdeau, J. (2007). Inside Theory-Aware and Standards-Compliant Authoring System, *Proceedings of the Fifth International Workshop on SWEL2007*, 1-18.

[7] Knight, C., Gašević, D., & Richards, G. (2006). An Ontology-Based Framework for Bridging Learning Design and Learning Content, *Educational Technology & Society 9*(1), 23-37.

[8] Sun, S., Joy, M. (2005). An Autonomous Multi-Agent Solution for Adaptive Education, *Proceedings of International Conference on Artificial Intelligence and Applications*, 622-626.

[9] Nkambou, R., Kabanza, F. (2001). Planning Agents in a Multi-agents Intelligent Tutoring System, *IEA/AIE*, 921-930.