A COMPARABLE FOUNDATION FOR ITS RESEARCH LOOP AND SUBFIELDS

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Abstract

Intelligent Tutoring Systems (ITS) are complex programs which are a popular research topic in teaching programs because they demonstrate the highest teaching efficiency. A benefit of ITSs is that you can replicate the same teaching style with the added functionality of an interactive and adaptive teaching program.

To understand how such an evaluation of teaching methods and ITSs is done, we visualized and analyzed the process of an ITS research loop. ITSs have to be created by a developer, who makes concrete decisions of the implementation. AI specialists, psychologists, teachers, experts of the teaching domain, knowledge engineers, UI/UX designers and so on are additionally involved. The product is an ITS which will be updated regularly. These updates can have an effect on the efficiency of the teaching methods. But rarely is the evaluation of the ITSs and the selection of teaching methods done. Normally a research paper about an ITS will evaluate a system in one specific state and the people involved in creating new ITSs will be influenced by this research. The problem exists when comparing two ITSs with different underlying implementation or teaching methods. In this case the factors that could have led to changes in the resulting teaching efficiency are multiplied, which are partly a fault of the research loop. Ideally, we want the same system with different teaching methods or the same teaching method with different systems.

We also analyzed how the ITS research field itself is divided and found 3 research categories. The first category is fundamental research, which specifies the basic knowledge of ITSs. The second is the implementation category — domain specific prototypes of ITSs (e.g. Mathematics or Language). The third, real-use adaptation, improves on existing ideas of large scale ITS use, profitability or usability without much technical knowledge.

Making ITS implementations more comparable can be achieved through a homogeneous fundamental specification. On the basis of the knowledge of the ITS research loop and the different subfields in ITS, fundamental research definitions can be made about the underlying learning material. The material is split up in two categories, because each must be handled by an ITS differently. One part is the passive learning content and the other part is the active learning content. These cater either to the presentation of learning material or the testing of the knowledge of the student. Verification of the student is possible through the evaluation of their action in a specific task. A process of the steps for using an ITS is defined, in which the passive learning content is taught before it is tested and the topic is evaluated through the active learning content. An ITS needs to adapt to the student, which requires in-depth understanding. This is possible through the analysis of the student's actions. Verification of the student's knowledge model helps to cement the ITS's assessment of the student.

The division of content is beneficial to domain experts because they can understand the implicit nature of how ITSs handle learning content. In contrast, the division will create better modularity and comparison to other modules for developers.

In conclusion we analyzed the current state of the process of creation and research, and their linking in the field of ITS. We divided the research field and proposed a division and clear definition of the learning material in the ITS process.

Keywords: ITS, meta, development, loop, foundation, categories.

1 INTRODUCTION

ITSs are systems that are excellent automatic teachers [1]. They are not as good as human teachers and maybe never will, but they lend techniques to teach from them, so they are close to them [2]. They teach through interactions with the student, which are mostly dialogs which feels like talking to a human [3] in a chat based visual form on a display. But it can also mean to control a simulated world.
the student is put in. They use AI to adapt its behavior and the learning content to the student to improve the effectiveness of teaching, since 1:1 teaching is the most effective teaching we have [4]. To be able to adapt to the student they need to evaluate him in regard to the teaching domain, for this they need more data than traditional e-learning systems. Instead of only the learning material, they also need the knowledge about teaching behaviors for the given domain and how to estimate the student with his preferences and his knowledge about the domain. Since it is not a learning system used by many teaching facilities, it still has to prove its value for a day to day use. Their goal is to be a good teacher, but their main use case may as well to produce many data for researchers to find the most effective teaching strategies for human teachers.

2 PROCESS OF RESEARCH ON ITS

Developing a new ITS is an immense effort, which is carried by very different stakeholders. In the end, it is software that needs to be implemented by a programmer. To make the best effort that the software developer knows what he implements, he will get a specification of the system from the stakeholders. These stakeholders do not have deep technical understanding of software creation, they need a different expertise. This leaves it to the programmers to decide how to implement the requirements in the ITS. As a result, the programmers develop an ITS and have to update the software either because of bugs, misunderstandings or because of later change requests through an updated specification. Even though most of the updates may seem like a small change, they could have greater impact to the students than initially thought.

Programmers can work after different life cycles of software development. There are several phases for all models, the iterative model is suitable for a complex software such as an ITS because it can respond dynamically to changing requirements, see Fig. 1. This process can also be applied to a larger view than just software parts, such as the specification of a target software. Thus, the developer is no longer the person who can design or test extensively. The burden of testing is put on the shoulders of researchers and the stakeholders have to design.

![Software development life cycle elements (SDLC) with components from [5]](image)

One goal of the ITSs is to measure the teaching efficiency other teaching systems and it is important to know how the educational researchers work. A typical scientific approach to measuring learning growth is listed roughly below.

- Random selection of subjects according to fixed criteria
- Create the same scenario
- Create a comparable control group
- Modification of one controllable attribute
- Observation and measurement of learning success in both cases
- Comparison of the groups
- Long-term observation

A researcher wants a consistent environment where only self-selected factors may change, that is a hard challenge for educational researchers. Therefore, it is disadvantageous if an ITS constantly evolves. A researcher has to choose one version of an ITS and let it be used by a high count of students and compare it to another way to learn. A version upgrade while testing could skew the results, he has to wait until a feature-complete version is available for him and estimate whether it is
comparable and error-free enough to be solely in one research. The researcher observes the student interacting with the ITS and publishes the results and its interpretation. Even if the ITS is used again in an educational research work, it is unlikely to be the same version. Since there is no restriction, everything could be replaced from one version to another or something that is not obvious for the researcher by has a high impact in the results. As the cycles of development and research are so diverse, it can be difficult to create a "software development cycle" between major changes where the next wave of development depends on the application of the software, see Figure 2.

![Figure 2: Influences of ITS development](image)

If one considers two strongly different ITSs without being based on a standard and uses them as a basis for carrying out one study at a time, this leads to further problems. The study is carried out by students who must interpret the tasks and the ITS, in addition, an instructor for the respective ITS will evaluate and interpret the interaction of the students with the ITS. Then the results of teaching research are published in scientific papers. Now, if we want to compare different teaching strategies in two different ITSs, where the ITSs itself are not comparable in multiple ways, then the research is not coherent, see Fig. 3.

![Figure 3: Equality problem of concrete ITSs](image)

Since there are already many communication problems and the goal of teaching research is not to compare different software systems, but instead examine differences in teaching styles, it is important that the underlying system is similar. It is assumed that a very different structure of functionalities or processes between the ITSs influences the measured values of the teaching researcher. Following is a list of the communication problems I found.

- Communication problem between stakeholders
- Communication problem from stakeholders to developers
- Communication problem from the ITS to the students
- Observation problem from usage of the student of the ITS to the instructors
- Understanding problem from the research papers to the stakeholders/readers

It would be beneficial if the programmer and the whole ITS adhere to a standard to have a positive effect on comparability. Most of the ITSs that are developed do not stick to any standard. One reason could be that there are not enough reusable standards that can be used as a specification for an ITS. So more and more newly developed ITSs, which differ from the basic structure of existing ITSs arise. Standards would represent a collection of improvement ideas, that can be adopted, and would create
mandatory requirements for ITSs. It would be possible to base assumptions on these ITSs because they have the same set of requirements. Without them an arbitrary selection of research may influence single ITS and create good looking results based on incomparable premises, which can distort the development of future ITSs and teaching outcomes.

3 SUBCATEGORIES OF ITS RESEARCHING FIELDS

Three research areas for research on ITSs were found in the analysis of existing papers about ITS. The boundaries of the areas are not sharply delineated, and that is a good thing, because the exchange of results from one area of research to another should always be present, yet they can and do exist independently in parallel. The researching fields are built upon each other; therefore, they also have a numbering.

3.1 Researching field 1: Basic research

The first area is the basic research for ITSs and answers questions that lay the basis for what ITS are and how they are useful. This is the most abstract and general research field, because it answers questions occurring in different types of ITS. Although the first area of research is not focused on implementation specifics, it may provide smaller prototypes to give proof of feasibility. An example ITS research paper of this field would be a general software architecture analyzed by the history [6]. Questions like the following describe the area well.

- What is the definition of a specific ITS?
- When should you use a specific ITS?
- What is a viable ITS architecture?
- What are historically successful ITS designs?
- What should you comply with when building an ITS?
- Which models are suitable for describing an ITS?
- Which processes exist inside and outside an ITS?
- How can you reuse the data gathered by an ITS?
- Which persons are important and involved in the development of an ITS?

3.2 Researching field 2: Implementation

The second section does much more work in implementing an ITS. Their software artifacts are intended to be used outside of the laboratory. For that they need to be focused on one expert domain to be able to create an ITS with a deep understanding of this domain. It requires good collaboration with teaching research in the chosen thematic area to apply the most appropriate teaching strategy to the chosen domain. Models of the first researching field are determined and there is a full feature, content complete ITS built upon on their specifications. Many implementation details have to be decided on which are influenced by concrete factors: the domain, the use case, the target user base, the size of the project and so on. These ITSs are mostly validated for their correctness and empirically evaluated in studies. An example ITS research paper would be [7]. The following questions the researchers ask themselves give an insight into this researching field.

- What is practicable when building one ITS?
- What is technically sensible when building one ITS?
- How good is a concrete ITS prototype?
- How do you map the knowledge of a domain?
- Which concrete technologies should be used?
- What is a good approach for a particular use case?

3.3 Researching field 3: Integration and results

The third section analyzes the existing ITSs. The main task of this research is to identify weaknesses and to find out and refine the best techniques for ITSs. It is being researched to expand application
possibilities, make adjustments to ITSs or their environment to allow easy integration of ITSs into
teaching. This field tries to make an ITS a viable sustainable product. Many real-world problems have
to be solved that are often not related to the quality of an ITS. This requires data about as many ITSs
as possible, so that the data on their use can be collected and analyzed. Since current ITSs are not
used in, research in that area is almost not existent. Researchers in this field should ask themselves
these questions.

- How to lower costs of development of an ITS?
- What is the most efficient use of an ITS?
- What are the best teaching methods for specific needs?
- Which teaching method can be extracted for reuse in human teaching?
- How to work together with human teachers?
- How to improve setup/installation of an ITS?
- How to improve the acceptance of ITS?
- How to scale ITS integration?
- What will and has prevailed in the long term and why?

4 SPLITTING OF THE LEARNING MATERIAL

For ITSs there are two kinds of learning material, which have to be designed fundamentally different to
be easily usable by the system. Both together are part of the domain knowledge an ITS has. One part
of teaching consists of explaining the necessary learning content. The second part is to test it and
allow more freedom of actions with the ITS. Interacting with the ITS through feedback from it while the
ITS is adapting through the answers of the student is the big benefit of such a system. It is not yet
possible for a software to ad-hoc generate interactive content out of static teaching material like
human teachers can. This means teaching material nowadays is divided into two categories:
interactive and informative teaching material. The following defines what the two terms mean.

4.1 Informative learning material

Informative teaching material is for presentation purposes. It is expected of the student to get an
incomplete understanding of the learning material. The recording of student knowledge is easier in the
informative learning material, because the possible actions of the student are much more limited. For
example is it in ITSs often registered and stored, what material the student has already seen and
possibly also other factors, including in which order and how long he has been viewing the informative
teaching material and if other referenced material was used. Specific examples of informative teaching
material are listed below.

- Textual explanations
- Audio recordings sometimes with table of contents and bookmarks
- Videos sometimes with table of contents and bookmarks
- Ontologies in one of the above forms
- Static virtual world with very simple interaction possibilities, for example a virtual museum,
  without the ability to change the world

4.2 Interactive learning material

This material offers the student a range of action options inside a given task and then leave it to the
student what he does or even if he wants to remain passive. But every meaningful action of the
student forces a feedback of the ITS and has an impact on it. The ITS needs to respond on the actions
of the student within a reasonable time and content. This learning material has to deal with a massive
variety of options the user has, so its design has to be much more open. Interactive teaching material
involves frequent interaction with the ITS. Tasks are ideal for the student if they automatically create a
dialog between him and the ITS. A teaching unit is then defined by informative and interactive
teaching material, which are both coordinated. The types of tasks can be manifold according to
Schanda [8] and Mair [9] as listed below.
4.3 Solution

An ITS has to be a tutor, this means that it should not just tell you the solution and letting you repeat it or leaving you on your own is not an option. It has to slowly increase the student's competence and explain why his errors are wrong. To work with the student in a for the student motivated and comfortable content and speed the ITS has to make an assumption about his knowledge and preferences. Knowledge transfer must be transmitted through a medium that provides the scope for interpretation, since the transfer itself can only happen with data and data has to be interpreted back to information and then knowledge [10]. This means even if the student did see all the informative lecture material, he may misinterpret the given data or not be able to remember them. In order to test whether the student's interpretation corresponds to what was expected, he must be tested on the basis of his actions with the interactive teaching material. It is a core part of ITSs to accurately diagnose students' knowledge and adapt itself to it [11]. Only using interactive learning material would leave the student on their own and negatively influence the learning speed and motivation, because students could choose to difficult tasks in the beginning or misinterpret the given learning material without any guidance. Interactive teaching material is therefore additional necessary for an ITS to be accurately adaptive through a precise student model.

5 FUNDAMENTAL ROLES IN AN ITS

There are different roles when working with an ITS instead of developing it. The most obvious are the role the ITS takes as a personalized automated teacher and the student as the person who needs to acquire the knowledge. But there are more than these two. The supervisor is the person who helps the student as a human when needed. While the big goal in the future is that the ITS as a whole can replace a teacher when needed, this is impossible in most domains. If the student has problems with the ITS, they can contact a person who explains what the ITS expects or provides technical assistance. The ITS should be designed to try to be intuitive and self-explanatory in the event of difficulties and recognize that the student needs more help than the system can give them. A supervisor is not a teacher, because he has no teaching background nor is it necessary for him to understand the learning content fully. He provides an external motivation for the student and should help to execute the correct flow of the interaction process with the ITS. Therefore, his education level does not have to be as high as that of a teacher and he does not have to be instructed neither didactically nor in the domain. This would save costs and in some parts of the world it is easier to retrain someone in a single process and dealing with a single ITS than finding a qualified teacher. In poor areas of Africa, it may be cheaper, more available and more effective to have no teacher locally and not to be given tasks by a teacher [12]. The list of actors is listed below.

- **ITS (Machine):** An ITS that is accessible locally or via a network connection and that teaches either informative and/or interactive teaching material.
- **Author (human):** A person who changes pedagogic knowledge or domain knowledge about programming or an author interface in an ITS.
- **Teacher (human):** A person who is locally or through a communication channel inside the automated teacher accessible to be of assistance in difficult situations.
- **Supervisor (Human):** A person who oversees students and helps implement the ITS process without teaching domain knowledge. Under certain circumstances, his task may be the supervision of the technical implementation.
- **Student (Human):** A person who learns the domain knowledge through the ITS.
There is a total of five basic methods of action: three methods of how to influence students and two methods of how to act on the ITS. These are listed below.

- **Presenting** (effect on student): Informative teaching material is presented, it is listed and explained with content tailored to the student.
- **Training** (effect on student): Interactive teaching material is worked through with the student (or more), it is a dialogue between both parties, instructors and students (students).
- **Supervise** (effect on student): The tasks of a supervisor are performed, including motivation and control without evaluating the content.
- **Knowledge Overhaul** (effect on ITS): Changing of the domain knowledge and the pedagogical knowledge of the ITS.
- **Help out** (effect on ITS): Overtake the teaching in a specific case to explain something to a student, where the ITS has come to its limits.

It is possible that the actors are local on site where the student is or only act by means of communication technology. A remote ITS could be implemented through a server application. Remote communication with a supervisor includes video telephony or a special program that can directly monitor or limit the interactions of students. The two options are enumerated below.

- **Local**: Actor is local to the student.
- **Remote**: Actor is connected to the student (the student) at a different location and via a technological communication interface to provide feedback almost immediately.

A human teacher is somewhat better than ITs [13]. Besides that, a human teacher can do much more than just to teach which influences teaching by being a caregiver for the student. Therefore, no supervisor is needed if a teacher is on-site (local). With a local teacher an ITS makes no sense, because a human teacher teaches better than an ITS. We found 30 different scenarios with only one student. These scenarios are combination of the roles, actions and its place available. Each of the scenarios can also be used in a collaborative way and with multiple students not working collaborative but on the same task at the same time, for example in a classroom supported scenario with a shared knowledge and shared ITS adaptation. So, there are more than 90 scenarios which are viable for use cases in teaching with an ITS.

6 CONCLUSIONS

We analyzed the current situation of the research and described the bigger iteration cycle of ITS. This research loop has its problems when it comes to comparability between different ITSs, because there are multiple steps where a misinterpretation could happen. Especially the ITSs itself are using various fundaments in their architecture, design, technical terms and so on. This can be misleading if we use the ITSs as a tool of measuring the effectiveness of teaching strategies. To reduce the differences, but keep the necessary and defining features, standards would be a solution. They would clearly define parts of ITS development. With standardized fundamentals between the different ITS they will become the best tool to find the best teaching strategies for human teachers, since they are able to indefinitely exactly mirror their previous behavior as a teacher in experiments with countless students working in parallel. This paper did not provide a standard but did describe the needed splitting of the learning material and shows all roles, their actions and the position in relation to the student which are used in ITS scenarios. These are many and only a fraction of them is used in ITSs available. This shows that there are many opportunities for new ITSs left. Research has to tell if they are effective. To give further research an easier entry into the research of ITSs. We presented the current 3 main fields of this topic. Their demands and needed work vary drastically. Notably research from non-software developers are important in this topic, instead of building a new prototype ITS, there should be fundamental research or research on what is missing to make ITS real products. Instead of only new concrete ITS software with new designs, research should focus on the basic research to establish more common ground.

REFERENCES


