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Case study title	ITS ANDES Physics Tutor (http://www.andestutor.org/)
Institution name	Andes was developed at the University of Pittsburgh and the United States Naval Academy with support from the Office of Naval Research, grant No. N00014-96-1-0260. Currently, the Andes project lives at Arizona State University with support from the Pittsburgh Science of Learning Center, National Science Foundation award No. SBE-0836012.
Reference person	Kurt Vanlehn. Professor of Computer Science and Engineering School of Computing, Informatics and Decision Systems Engineering Arizona State University (Email: kurt.vanlehn@asu.edu).
Background	ANDES is a system Algebra Subsystem for an Intelligent Tutoring System. It has been developed by researchers at the Learning, Research, and Development Center (LRDC) at the University of Pittsburg and the United States Naval Academy since 1996. It is freely downloadable from http://www.andes.pitt.edu/Install/Download.html. ANDES includes more than 500 problems, covering most of the topics in on trigonometry of a physics course at university level. Target of Andes are students in courses at the college level in classical physics. It allows students to solve physics problems (static forces, translational and rotational kinematics, translational and rotational dynamics, work and energy diagrams and equations necessary to solve the problems). The focus is the improve instructor/student interaction in the classroom and the interaction of the student with the subject of physic in the context of doing homework. In particular, Andes has been used for students at the United States Naval Academy (USNA) for the introduction to

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	physics and helps the student to learn Newtonian mechanics. This intelligent tutor allows students to solve physics problems in an environment that provides visualization, immediate feedback, procedural and conceptual help.
Intended outcome(s)	The researchers observed the difficulties of learning physic from the students in high school. This subject have an important role in higher education and to better prepare experts. However, although many of students study physics, most of them do not archive an advanced level of knowledge in the field: many students find the problem-solving skills, important in a physics course, difficult to develop. Students appear to learn much more when personal tutoring is available as they attempt to solve homework problems. The problem of major textbook or simple tutoring system is that they provide very little guidance to the students when they are trying to solve a problem: as the researchers note, working on homework assignments without the benefit of expert feedback is often a frustrating experience. So, for VanLehn at others researchers the intended outcome with Andes is to construct an intelligent tutoring system able to provide immediate feedback and relevant hints to students. In summary, Andes have two main goals: a) to replace the students' pencil and paper as they do problem-solving homework; b) to improve the acceptance of ITS in the class without extensive modification of the course content. Kurt VanLehn *et al.* (2005, p.2) claim: "The goal of the Andes project is to demonstrate that intelligent tutoring can be decoupled from content reform and yet still improve learning. This requires that Andes be minimally invasive. It should allow instructors to control the parts of the course that

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	they want to control, and yet it should produce higher learning gains than ordinary courses".
Technological development	The project Andes was founded by the Office of Naval Research in the United States in an attempt to test the ITS for professional training. Andes arose from the ambitious project to build a new physics tutor on the foundations of the Cascade (a rule-based cognitive model of physics problem solving and learning, capable of solving many physics problems in a variety of correct and incorrect ways – VanLehn & Jones, 1993) and OLAE (an on-line assessment system, with a graphical user interface and a student modeling module – VanLehn & Martin, 1998). An early version of Andes used a Bayesian logic, to infer the probability of mastery of each rule (assuming two status: mastered or unmastered): Andes1 was one of the first large scale applications of Bayesian networks to intelligent tutoring systems. In 1999-2003Andes has been tested in an introductory physics course at the U.S. Naval Academy, and then used as part of the normal course where students were encouraged to do homework with Andes. In the control section, similar tasks were used but without the use of Andes. At the end, all the students achieved the final exam: in all test students who had used Andes, showed the highest results, in particular in some activities like "Drawing" and "Variable definitions" during the resolution of equations. After the positive outcome of the testing phase, researchers focused on improving the pedagogical features of Andes. The research in subsequent years enabled the group of VanLehn to develop "Andes 2": the Bayesian networks were eliminated while retaining the non-probabilistic aspects of

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	the student modeling module; the new system also featured a new, more concise knowledge representation and many other improvements (like electronic submission of homework and automated problem scoring). The new system introduced a better representation of the domain specification, bringing to 356 the problems that are solved by a knowledge base of 550 rules of physics, improving thus the simplicity of the system. The authors believe that natural-language processing is necessary for encouraging deeper learning. The project Atlas (developed at Pittsburgh's Learning Research and Development Center) contains natural-language-based enhancements for model-tracing tutors that are modelled after human tutorial dialogue. The challenge declared by researchers is to incorporate Atlas into Andes.
Piloting	Andes is constituted by an expert model and a student environment. The expert model incorporates the physic domain knowledge and pedagogical strategies that are the foundation of Andes. The knowledge in the expert model and pedagogical strategies which guide the tutor were provided by three professors of Physics at the United States Naval Academy (USNA) with a lot of experience. The student environment, developed by the researchers at the LRDC, incorporates the interface, the student assessment and the help system. A formal assessment of Andes was conducted at the Naval Academy in the fall semester of 1999. The assessment included 173 students using Andes as a part of their course work and a control group of 161, all of whom were taking the required general-physics course. The assessment tool was a 400-point, free-response examination that covered the first

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	eight weeks of the course. When the raw scores were converted into percentages, the Andes group scored about 3% higher than the control group. In practical terms, this corresponds to about a third of a letter grade, which in an academic context is notable. Obviously, one goal of the project is to maximize this improvement. A statistical analysis was performed, comparing the Andes group to the control group. The results showed that the Andes group was better than the control group: the improvement using Andes is statistically significant.
Teaching and Learning Implications	In general, the basic principles of its design are (Gertner & Van Lehn, 2000): ✓ encourage the student to construct new knowledge; ✓ adopt a family structure as the work on paper; ✓ provide suggestions and feedback after each action; ✓ provide flexibility in solution and performance of a task. There are two main phases of use of Andes for a physics problem: 1) the preparatory phase of the formal description of a problem, with a set of constraints and variables; 2) production of a file that contains all solutions, with a list of the different variables of the problem. In this way the information is stored on how to solve the problem. In this way, Andes is able to provide a form of tutoring to solve the problem. The interface, referred to as the Andes Workbench, provides an interactive environment in which the student works the physics problem with multiple tools. The user interface allows the student to draw vectors and write equations "in order to make Andes' user interface easy to learn, it is as much like pencil and paper as possible" (Van Lehn, 2005). Specifically, students read the problem (in the

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	upper part of the window on the top left), drawing vectors and axes (lower part of the window on the top left), define variables (top right window) and inserting the equations (window at the bottom right). The green colour for the right solutions and the red colour for the wrong ones are used. Variables and vectors must be defined before they can be used by clicking on the toolbar. For example, when you define a force, the student uses the menu to select two objects: the object which the force acts and the object to which the force is directed. The student model is updated at the end of each problem (Conati, *et al*. 2000; VanLehn, *et al*., 98). This model maintains the probability that a student understands specific physics concepts. For example, if a student has successfully solved several problems involving Newton's Second Law, then the student model will reflect that she has mastered this concept. However, if Andes determines the student does not understand a concept such as the normal force, a short lesson explaining that concept will appear on the screen. Andes provides three types of support: ✓ An error message appears when the mistake is probably due to the lack of attention rather than the lack of knowledge. ✓ The student can require support by selecting the red button and then clicking "help" button. ✓ If the student is not sure, he/she can click on the "Next Step Help" to receive advice on how to proceed. The peculiarity is this: ✓ for errors that may be due to distraction Andes provides assistance not required; ✓ while the errors into which learning is possible,

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	Andes provides support only when required. This strategy boost the self-assessment of students and lead to a deeper reflection on the understanding the error. As the student solves a problem, Andes calculates and displays a score: the rating is a function of the degree of correctness of the problem; the number of tips and accuracy for the explicit inclusion of information. Andes can be used both offline and online, allowing you to send real-time results to the teacher. For the design of problem-solving, has been adopted this didactic principle: the subject have to master all principles of a subject, whether general or particular (in line with the literature that suggests this as the main difference between experts and novices). For this reason, some features have been outlined Andes to reach full understanding of the principles of the subject: - *Propose a wide variety of problems*: given the multiplicity of tasks available in the software. - *Authoring tools*: in order to facilitate the explicit definition of the problem, allowing a deeper understanding of the same. - *Learn to communicate accurately*: Andes is very specific and exact. For this, strategies of introduction to topics are used, such as for example the video presenting examples resolution. - *Macro-modeling and adaptation of the students*: the system decides on the level of difficulty of the next problem, according to the monitoring of students' performance: in this way the students can improve his zone of proximal learning. - *Scaffolding*: it is not too rigid because usually home tasks are carried out without supervision. To keep motivated and avoid forms of frustration to the students during the

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	resolution of homework, the final score given by Andes is positive (thanks to the numerous feedbacks and suggestions give by Andes during the exercise, which contribute at a high score). The authors believe that this educational strategy is used to activate students' motivation. -*Unintelligent help*: it provides suggestions not required, particularly when the student is seeking information. -*Reasoning requested*: emphasis is placed on the reasoning required to reach a solution to the problem. Finally, an important part of design of Andes is on the "Feedback": - *Flag feedback*: use of red and green colour for incorrect or correct answers. - *What's Wrong Help*: looks like a light bulb that provides additional information and tips. - *Hint sequences*: provide suggestions based on the level of difficulty of the problem. Future versions will provide more substantive scaffolding such as requiring that students construct free-body diagrams before entering equations.
The e-learning advantage	Technologies mediate people's interactions with the world and become inseparable from the process of human learning. The diffusion and the increasing competitiveness of online interventions by educational institutions has led to a growth of attention to learning environments that make possible such interventions. In particular, to support the needs of the user, the research is oriented towards the innovative tools, supporting the quality of learning in a personalized learning path. Andes supports self-learning whit specific pedagogical supports: “Andes has many features, both large and small, that are intended to accelerate students’ learning” (VanLehn,

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	2005, p.45). Several pedagogical issues were considered in the design of Andes: ✓ Correct misconceptions: some students even hold false beliefs. Therefore the interface was designed to encourage students to follow successful problem-solving strategies. For the student Andes have a very useful strategies: for example, this compilation mode forces students to precisely define the variables and vectors, leading to a more precise reflection. The characteristic is that the student proceeds as he was writing on a sheet and the system operates only when the student has need of suggestions. ✓ Interaction is flexibility in the allowed solution path: one of the primary goals in developing the knowledge base was to provide a tutoring environment that allowed the same kind of student/tutor interaction that might be experienced in a one-on-one session with a professor: for example, flexibility occurs when it is possible to solve a problem in two different ways, and in this case, the knowledge base will generate both solution paths and the corresponding equations for each path. This flexibility allows the student to determine her solution path without being forced to solve the problem in only one way. ✓ Andes gives the opportunity to reconstruct the correct sequence of learning is also a necessary element in line with the strategies of cognitive memory, facilitating the retention of memory and the generalization of the principles, presenting the

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	suggestion in a context of already known, facilitating recovery; presence of examples.
Key points	A basic aspect of Andes is to facilitate the student with algebra problems to devote more attention to the learning of physics. In general, the Andes is able to diagnose multiple solutions and provide suggestions based on the solution adopted by the student. The key point of Andes is in the possibility of interaction with the student, being able to (Shapiro, 2002): 1) to solve equations in physics problems; 2) to verify the validity of the equations of the students; 3) to investigate if the equation is independent of a set of equations; 4) to provide tools to help the student to solve equations. For other practitioners, Andes is considered difficult because it uses a precise strategy for both students and instructors. There is a need of a training before its use.
Conclusions and recommendations	Van Lehn (2005, p.43) says "It appears that we have succeeded in finding a way to use intelligent tutoring systems to help students learn while replacing their only paper-and-pencil homework.". Much emphasis is given to how Andes can be applied to any curriculum without changing their use, but adapting adequately. In conclusion, Andes turns out to be a tool that allows students to start a process from "novice" to "expert". Its use, however, needs to be supported by a teacher to motivate students in its use, slowly mastering the complexity that characterizes this complex but useful ITS.
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