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A Theoretical Background on a Successful Implementation of Lecture-Tutorials

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Abstract

The curricular and pedagogical properties of Lecture-Tutorials for Introductory Astronomy are discussed. These properties are combined with aspects of the Eccles et al. concept of subjective task value to create an interpretive framework for a successful implementation of Lecture-Tutorials at the classroom level.

1. INTRODUCTION

In the quest to engage non-science-major students in astronomy and foster positive attitudes toward science in general, the Lecture-Tutorials for Introductory Astronomy (LTs) (Adams, Prather, & Slater 2005; Prather et al. 2003) can be very effective. In the past three years, I worked as a teaching assistant in introductory astronomy classes that used the LTs with great success. Students regularly noted, both in class and on end-of-semester evaluations, that they considered the LTs to be fundamental in their learning and that they really enjoyed them. Prather et al. (2003) reported on the cognitive gains obtained by the students in similar classes. However, like all curricular materials, the LTs are not immune to transfer factors. What works well in one educational setting may not necessarily work well in another. Faculty report that they find implementing the LTs in their introductory non–science-major astronomy classes more challenging than they thought it would be (E. Dokter, personal communication 2006). For a successful implementation of LTs, several conditions have to be met simultaneously. In this article, I will describe the properties of the classrooms that I worked in as a teaching assistant and place these properties in a learning theoretical context to show how the individual properties work together to form a learning environment in which the LTs can successfully be used. I do not claim that the implementation I describe is the only correct one, just that it turned out to be successful.

This article is set up as follows. In Section 2, I briefly describe the LTs. In Section 3, I outline the main ideas of the constructivist and conceptual change theory that form the educational basis of LTs. In Section 4, I describe the implementation of LTs as I witnessed them and put aspects of the implementation in a theoretical framework. In Section 5, I discuss the concept of subjective task value, which I offer as an overall theoretical framework to interpret the implementation of LTs. Conclusions are drawn in Section 6.

2. PROPERTIES OF LECTURE-TUTORIALS

LTs are short activities, typically taking between 10 and 20 minutes of class time. The LTs do not contain explanations or background paragraphs, but are intended to be used as support materials. There is not enough information in the LT to serve as a substitute for lecture or other forms of curriculum.

The educational philosophy behind the LTs is based on constructivism and conceptual change, which are explained in more detail in Section 3. The LTs were developed with known student misconceptions and reasoning difficulties about concepts in astronomy in mind. The questions in the LT are designed to systematically elicit student ideas, confront misconceptions and reasoning difficulties, and help students resolve these in order to facilitate conceptual change (Driver 1989; Posner, Strike, Hewson, & Gertzog 1982). The LTs use a loop-back system in the questions, in which students are repeatedly asked to look over previous questions to see if they still agree with the answers they gave. This serves as a safeguard against the formation of multiple representations in the students' minds (Redish 1994).

LTs are written in natural language rather than more formal science language. This is done because the context in which a particular problem is framed is very important. Research by Palmer (1993, 1997, 2001) has shown that conceptually equivalent questions are responded to differently when the setting of the problem is changed. For example, in physics, this means that if the problem is stated as a "physics problem"—abstract, mathematical, and not related to a real-life situation—the probability of the student using the correct mental model is higher than if the problem is stated as something practical that has an everyday-life application. If phrased in everyday langauge, students are more likely to fall back on their misconceptions, which are based on their personal experience. In addition, Clark and Rutherford (2000) found that the actual phrasing of questions in activities or assessments could influence students' choices as well. If students can undergo conceptual change in natural language, the effect is arguably more powerful than if they undergo this change in formal science language. The risk with the latter is that students will use multiple models, one for formal language and one for informal language (Redish 1994).

3. CONSTRUCTIVISM AND CONCEPTUAL CHANGE

When students enter a classroom, they have multiple years of educational situations, both formal and informal, behind them. These educational situations will have led to certain ideas about the world and about the material that will be taught (see, for example, Driver 1989 for a review). Constructivism is the learning theory that states that new knowledge is built on prior knowledge. Students' initial ideas are not necessarily in line with the commonly accepted scientific view. When instruction in classrooms is building on this incorrect prior knowledge, the end result of that instruction will most likely be incorrect as well.

Another caveat is that prior ideas do not have to be exactly formulated. They can be a loose set of ideas in the heads of students. Because the ideas are so vague, it is perfectly possible to have conflicting ideas about one concept at the same time (Redish 1994). When confronted with a novel situation, students will apply pieces of knowledge that seem to be useful and devise a model to deal with the situation on the spot. An example, as shown in the video *A Private Universe* (Schneps & Sadler 1988), is the cause of the seasons: a majority of people claimed that it is warmer in summer than in winter because we are closer to the Sun in summer. diSessa (1993) introduced the term "phenomenological primitives," or p-prims, to describe this phenomenon. P-prims are deeply entrenched, very basic ideas about the world that can originate from the sensory-motor stage in early childhood development. One example of such a p-prim is "close means more," an example being that when you get closer to a hot stove, it gets warmer. This is a concept that we learn at a very young age, and it is deeply entrenched in our thinking, so it should be no surprise that such an idea interferes with learning, like Schneps and Sadler demonstrated. Because these ideas have been so useful to students in the past (they kept them from getting burned, in this example), they tend to be resistant to change. Even after instruction, students hold onto their ideas about the world. In classrooms, we commonly see that students have the right concept in mind in class but will use their own concepts when out of the classroom setting. The dichotomy between the in-class notion and real-world notion can be huge.

In the cognitive model of Information Processing and Problem Solving (IPPS) (see, for example, Good & Brophy 1995), p-prims, ideas, schemas, and preconceptions, which have settled into students' brains during their lives, are part of their long-term memory. The long-term memory influences the perceptional filter, the mental "glasses" through which an individual sees the world. This filter "colors" new experiences in the sense that these experiences will be interpreted based on already existing knowledge of the world and how that world operates. In the case of a misconception, the perceptional filter will thus color the experience in a wrong way, hampering understanding. A theory used to deal with incorrect models, misconceptions, and reasoning difficulties was outlined by Posner et al. (1982). They looked at the circumstances under which conceptual change, the transition from one mental model to the other, can take place. Posner et al. claimed that there are four factors guiding conceptual change. First, there must be dissatisfaction with the existing concept. Second, the alternative for the concept must be intelligible; it must make sense to the student. Third, the alternative for the concept must appear initially plausible; in other words, it must have high face validity. Fourth, the alternative for the concept should be fruitful; it must allow for further exploration.

As mentioned previously, the LTs are designed with student ideas in mind. The LTs use the knowledge of student misconceptions and reasoning difficulties to systematically elicit, confront, and help students resolve them. The sequencing of questions is chosen such that it forces students to reflect on their thinking.

For an instructor, it thus becomes relevant to know what sort of misconceptions and reasoning difficulties students are likely to have, otherwise the instructor may fail to see the relevance of certain questions in the LTs and will not be able to adequately assist the students. Some of these misconceptions and reasoning difficulties are presented in the teacher manual, which is available through the publisher. In addition, the instructor should know of multiple ways to deal with misconceptions and reasoning difficulties in order to accommodate a variety of student learning styles. In other words, instructors need to have a fair amount of pedagogical content knowledge (PCK) (Shulman, 1986, 1987), a form of specialized craft knowledge to mold content (astronomy) knowledge into a form that is suitable for teaching (Van Driel, Verloop, & De Vos 1998)--the translation of knowledge into curricular events (Carter 1990).

4. THE LECTURE-TUTORIALS IN THE CLASSROOM

In addition to a constructivist and learner-centered learning environment and instructor PCK, both of which were present in the classes in which I was an assistant, I witnessed several other elements that helped make the implementation of LTs successful:

- The emphasis on LTs in both the classroom and on the assessments
- A noncompetetive learning environment
- The use of LTs as a reinforcement tool
- Instructor use of Socratic dialogue during the LTs
- Time management and debriefing of the LTs in class
- Office hours as an integral part of the course

The classes typically enrolled about 150 non-science-major students, and the LTs were used on nearly a daily basis. After some period, typically between 20 and 30 minutes into the lecture, the class would turn to an LT on the same topic. The LTs were used purely as reinforcement tools. Students were instructed to work in small groups, preferably pairs, to discuss the questions and solve them together. During the LT, which normally took between 10 and 20 minutes, the instructor and the teaching assistant(s) walked through the room and assisted groups who got stuck. People who did not participate were actively confronted and put back to work. The instructor and assistants used Socratic dialogue techniques to help students. Time constraints on the LT were strict, and not all students finished the LT in the allotted time. After the LT, the instructor went over some of the most common problems in class and then told the students that they should finish the LT on their own and that office hours were available for those needing further assistance. Apart from these most common problems, no answers to LT questions were given. Normal lecture resumed after the LT for the remainder of the class period. Next, I highlight some of the characteristics described above.

4.1 General Class Policies

In a constructivist learning environment, in which students have to be active in class and make sense of the material for themselves, friction can occur. Constructivist activities, such as the LTs, violate the "hidden contract" in education. The hidden contract means that students expect, based on their past experiences (e.g., in high school or other college courses), to be able to memorize facts, regurgitate them on the test, and get a good grade. The instructors in the classes I worked in made it abundantly clear, both in their syllabi and in class, that rote memorizing would lead to failure in the class. At the beginning of the semester, the instructor told the students that the philosophy of the class was for them to be active, participate, and work with each other to acquire a deep understanding. Grading in these classes was done on an absolute scale rather than a curve. The reason for this is that curving puts students in competition with one another for high grades; it decreases the motivation to work together, whereas the intention is to have students collaborate and learn from each other.

The instructor warned that the LTs were a vital part of the course and that 70% of the exam questions would be derived from the LTs. The reason for having such a high percentage of the exams (and thus the final grade) depend on the LTs was to provide an external motivator to do the LTs. Students would not be able to pass the class without doing, and understanding, the LTs. By making clear the expectations and the route to success in the class, the instructors lessened the chances that students would try to engage in task negotiation about the LTs. Doyle (1983) discusses the concept of task negotiation in relation to the level of ambiguity and risk of the task. Ambiguity means the level to which a precise answer can be defined or that a precise algorithm for getting to an answer is available. Risk means the level to which students are held accountable and the likelihood that the accountability criteria can be met. If a task is of high risk and high ambiguity, students will have a tendency to negotiate the environment of the task to lower risk and ambiguity.

4.2 Reinforcement Tool

As mentioned earlier, LTs do not contain enough information to be used as standalone curriculum. In the implementations of LTs that I worked in, they were strictly used as collaborative in-class activities. They were never used as (graded) homework. Part of the reason is that different uses of LTs change the nature of the academic task. The concept of academic task was put forward by Doyle (1983). An academic task consists of three parts: the product that students are to create, the operations that should be performed to generate the product, and the resources available to the students in generating the product. Regarding use of LTs as an in-class reinforcement activity, the product is a completed set of answers to the questions, the operations are the peer instruction and discussions, and the resources are both the other students and the material covered elsewhere (lecture, lab, and so on) to help answer the questions on the LTs. But should the use of LTs in the curriculum change, the academic task changes as well. For example, when LTs are used as homework, the product changes (a focus on correct answers rather than on the thinking process), and the resources change as well (students working on their own rather than being able to help each other). Because the LTs focus on reinforcing conceptual change (a thinking process) rather than on producing correct answers, the instructors for whom I was an assistant opted to use the LTs as reinforcement activities, with the peer instruction from the students working collaboratively.

4.3 Socratic Dialogue

The use of Socratic dialogue techniques is one of the more difficult things to learn as an instructor, and it requires considerable practice. When students are stuck on an LT, there is substantial temptation to repeat a part of the lecture and to give students the answer. As instructors, we like to be helpful. However, it is the students who should expend the mental energy, not the instructor. Students need to go through the challenge of learning the material themselves. When students reason out a problem by themselves, it not only results in deeper understanding, but it also tends to give them a strong boost in self-efficacy (Bandura 1986, 1997) and self-confidence, especially for those students who have math and/or science anxiety. Typically, questions like these can be asked of students who are having difficulty:

- *Can you read me the question?* Often, misunderstandings arise because students don’t read the question well. By forcing them to read the question out loud, those misunderstandings routinely vanish. From my experience, about half of all student questions can be solved in this way.
- *What is happening?* Students sometimes have an unclear understanding of what the situation is about, what a cartoon is depicting, and so on.
- *What makes you think that?* Students often just give an answer and then look expectantly at the instructor for signs of approval or disapproval. By not saying right or wrong but actually asking for a reason why they gave an answer, instructors force students to examine their own thought processes. Too often, the first response to this question is, "I don’t know."
- *What is it that you don’t understand?* A blanket statement "I don’t know" or "I don’t understand" is not very informative. Often, a whole pattern of reasoning is needed to answer a question. By examining each individual step, the instructor and student learn where the misunderstanding or reasoning difficulty lies, and follow-up statements or questions can be formulated to address these.

4.4 Allotted Time, Debrief, and Office Hours

LTs typically take between 10 and 20 minutes to complete. However, students will take as much time as they are given. Giving students slightly less time will increase the pressure to keep on task. There is a fine line, though. If not enough time is given, the task of completing the LT becomes impossible in the eyes of the students. This will lead to a decrease in intrinsic motivation to engage in the task (see Schultheiss & Brunstein 2005, and references cited therein). As a side effect, students will have a tendency to start working on their own as a perceived means of improving efficiency (not having to talk to their neighbor). This is contrary to the pedagogical effectiveness of the LTs, which relies partly on peer instruction.

Students often request answers to the LTs to be handed out. However, several motivational arguments can be brought against this. First, when students know that answers will be given at the end of the LT, the motivation to actually engage in the activity will drop. Knowing that no complete set of answers will be given increases the motivation to talk to one another to get the answers right. Moreover, giving out a set of answers will increase the chance that students will rote-memorize the answers (as part of the hidden contract mentioned earlier) without trying to understand the concepts underlying the answers. Students always had the option to visit the instructor or assistants during office hours if they wanted to know if their answers were correct. This puts the responsibility for learning and understanding back on the student. The downside of not giving out answers is that it gives the students an opportunity to attribute failure externally. In the framework of academic work (Doyle 1983), not giving out the answers increases the task risk but not the ambiguity. It is still clear that the students will be held accountable for the material (low ambiguity), but not doing the LT in class when one has the opportunity or not taking the time to reflect on the material will increase the chance that the student will not do well on the test (higher risk for not doing the LT). However, the instructors in the classes felt that increasing the task risk was preferred over giving out the answers, for the reasons listed above.

5. SUBJECTIVE TASK VALUE AS A MOTIVATIONAL FRAMEWORK

Before a student can start actively learning the materials discussed in lecture and the LTs, he or she first must be willing to actually engage with the materials. Several of the aspects discussed above already hint at that. In a sense, this is a motivational issue. Subjective task value, a component of the Eccles et al. (Eccles [Parsons] et al. 1983; Eccles, Wigfield, & Schiefele 1998; Wigfield & Eccles 1992) expectancy-value model, can be used as a theoretical basis to investigate how to motivate students. It provides a schematic overview of the elements that go into a person’s decision to engage in a task (academic or another type)—in this case, the student engaging in an LT. Subjective task value has four main components, and the higher the subjective task value, the more the person values engaging in the task. The first component is the attainment value; the higher this value, the more a person values the outcome of the task. The second component is the utility value; the higher this value, the more the person sees the practical use of completing a task (e.g., mastery of a skill that is deemed useful). The third component is the perceived cost. What are the costs in time, effort, and energy that the person must expend to complete the task? The lower this value, the higher the motivation to engage in the task. Conversely, if the cost becomes too high, the subjective task value will drop. The fourth component is the intrinsic motivation; how much is a person motivated, without external influences, to engage in the task?

Intrinsic motivation itself is mediated by three factors from self-determination theory (Deci & Ryan 1985). Self-determination theory deals with fundamental needs in humans. If these needs are met by engaging in a certain task, people will feel more intrinsically motivated to engage in it. These needs are competence (the perceived ability to do a task); autonomy (a sense of being the master of one's own destiny and being able to make choices); and relatedness (the sense of belonging and social closeness).

The expectancy-value model and self-determination theory hint at elements for successful implementation of the LTs. The subjective task value should be as high as possible to motivate students to engage in the task. Several things can be done to achieve this:

- When LTs are done in pairs or small groups, it increases relatedness, which increases intrinsic motivation, thus increasing the subjective task value.
- Successfully working on LTs, confronting and resolving one's misconceptions and reasoning difficulties, increases feelings of competence. This increases intrinsic motivation and thus the subjective task value.
- The greater the emphasis on the LTs in assessments, the higher the perceived cost of not doing the LT. This increases the subjective task value directly, but also indirectly by affecting the attainment value, depending on whether the student is motivated by a desire to obtain a high grade in the course.
- Keeping time pressure on the students during the LT means that they have to remain engaged in the task in order to complete it. If they don't succeed in completing the LT during the allotted time, they should have the opportunity to finish it later (e.g., during office hours) to avoid creating an impossible task. Tasks that are not possible to complete successfully within the (total) time given lead to a decrease in intrinsic motivation. A good task is challenging but not impossible. If too much time is allotted for the LT, students will grow bored, leading to a decrease in motivation to engage in this task in the future.
- Office hours can be very useful to create rapport between instructor and students, and among students. In big classes, students can feel anonymous. Knowing the instructor or fellow students can give them a sense of relatedness and increase their intrinsic motivation to work on the LTs.

6. CONCLUSIONS

What makes LTs successful? How can they be used in a classroom to the most effect? In this article, I looked at some of the motivational factors that go into a successful implementation. First and foremost, the environment of the classroom has to be set to accommodate LTs. A constructivist, conceptual-change-driven classroom in which the students are not in competition with one another for high grades (grading on a curve) is of prime importance. Second, it is important for the instructor to know what types of misconceptions students have, how they are addressed in the LTs, and how misconceptions and reasoning difficulties can be resolved. In short, the instructor should have a decent amount of astronomy pedagogical content knowledge. The implementation of LTs feeds several motivational factors that influence the subjective task value for students. When done well, the LTs can help students overcome anxieties about science and help promote self-efficacy. The extent to which these factors interact and how flexible an implementation of LTs can be before the learning goals of the LTs start to become compromised is unclear at this point. More empirical research needs to be done to verify and expand the motivational issues set forth in this article.

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