Analysing Student Reflection in *The Learning Game*

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Abstract. Supporting student reflection is one of the goals of inspectable student models (ISMs). Several researchers have studied student reflection using a variety of strategies to support interaction with the student model. We explore student reflection using a general educational computer game environment called *The Learning Game*. *The Learning Game* provides tools to interact with the student model, mechanisms to integrate and propagate evidence, and feedback of different sorts. A taxonomy of reflective actions has been defined and used to examine evidence of student reflection in *The Learning Game*. Results show the existence of student reflection. Different learning activities can be used to support different degrees of student reflection. High degrees of student reflection are associated with students revisiting concepts and receiving appropriate feedback.

1. Introduction

One of the main goals of inspectable student models (ISMs) is to support student reflection. Researchers have explored different strategies to achieve this goal. Strategies used vary in terms of the degree of intrusion and sophistication. For example, Kay [13] makes available the student model and provides tools to support scrutability, integration of evidence and conflict resolution. In Bull et al. [7] students are required to provide self-assessment, give and receive feedback from a peer, and explore the system's beliefs. Bull & Pain [6] explore students negotiating and discussing the student model with the system. In Morales et al. [14] students use a computer-based simulator and a special graphical interface to interact with a student model composed of a set of rules. The student model is updated based on the student's behaviour while using the simulator. In Dimitrova et al. [10] students are guided through a constructive dialogue process in which the system can switch between different diagnosis tactics. Although these researchers use a variety of strategies, most of them report that students explored the student model and evidence of student reflection was found.

On the other hand, Dillenbourg [9] states that the mere existence of reflection tools does not imply that students reflect on their learning experiences. Similarly, in promoting self-explanations, Aleven and Koedinger [1] report that using a simple menu driven graphical interface in which students could explain their answers was not effective. In fact, Aleven and Koedinger state that instructional guidance or some form of tutoring dialogue mechanism should be provided in order to promote self-explanation [2].

Our previous work suggests that using several guidance mechanisms to support student interaction with the student model, students become engaged in a reflection process that involves activities such as looking for more information about the domain content using various media, interacting with human classmates or artificial agents in order to learn more about some topic, asking the teacher for an explanation, or defending their position using verbal or written explanations [18].

In this paper, we further explore student reflection by using a computer game environment called *The Learning Game*. *The Learning Game* has been created based on a framework for learning environments based on inspectable student models [15]. A taxonomy of reflective actions has been defined and a study using *The Learning Game* has been carried out. This paper reports on the results regarding student reflection.

2. A Framework for Learning Environments based on Inspectable Student Models

Barnard and Sandberg [3] propose a methodology for open learning environments in which the learner is located at the centre of the learning environment. Although a detailed model of student knowledge is not stressed in Barnard and Sandberg's description of open learning environments, they offer specific opportunities for acquiring and updating the student model (i.e. students' aptitudes and preferences.)

In open learning environments the student may be directly asked for information and can be given direct access to pieces of the student model. In fact, Barnard and Sandberg recognise the importance of modelling the learner in order to use this information in self-evaluative activities. They also appreciate the idea of making the student model available to the learner and considering the interpretation of the model an issue of negotiation. By considering the learner as an equal partner in the interaction with the student model, open learning environments place more responsibility on the learner. As a result, open learner environments should broaden the content of the student model in order to take into account additional variables the learner believes affect his/her learning process. In addition, issues of privacy, accessibility and control should be considered in this kind of framework.

Several problems were identified when learners interact with open learner environments. The major problems reported are as follows:

- lack of self-assessment and insight into the learner's own learning process,
- difficulties constructing one's own knowledge and acquiring deep knowledge,
- making effective use of information resources, and
- co-operating with fellow learners in order to improve the learner process.

The problem of lack of self-assessment found in learners interacting with open learning environments is fundamental due to the higher degree of responsibility invested in learners to direct their learning process. Barnard and Sandberg propose three actions to overcome this problem. First, provide learners with the means to undertake self-assessment. Second, investigate how learners make use of such means. Third, investigate how learners can be stimulated to use the facilities offered in a fruitful way. Our research suggests that inspectable student modelling tools (ISMTs) such as ViSMod [16] and various guidance mechanisms could be used as to empower learners with the means to undertake self-assessment (following Barnard and Sandberg's first suggestion). In addition, an extension of Barnard and Sandberg's framework for open learning environments that integrates inspectable student modelling tools and guidance mechanisms could be used to investigate how learners interact with such tools in order to support self-assessment (Barnard and Sandberg's second suggestion). Finally, using such a framework for learning environments based on inspectable student models, different experiments could be carried out in order to investigate how learners can be stimulated to use these tools in a fruitful way (Barnard and Sandberg's third suggestion).

We propose a framework for computer-based learning environments based on inspectable student models [15]. This framework builds on Barnard and Sandberg's general model of a learning environment by integrating a technological platform that both human and computational components in the framework can use to interact with student models. Human learners and teachers in the framework are empowered by using inspectable student modelling tools that aim to support student motivation, refinement of student models, student reflection, and different kinds of assessments.

Computational components include ISMTs, artificial students, artificial tutors and coaches, and other educational software tools and computer-based learning environments that provide learners access to learning materials. These components use the student model information in order to customise their interaction with a particular learner on a particular topic. Student model information is available through a student modelling server platform [17].

This framework is conceived within a socio-cultural niche, which includes information about the community in which the learner interacts (i.e. a virtual or a real community). This information includes the learner's social, economical and cultural background. This information is used by the components in the framework to create a meaningful and a suitable interaction with the learner.

Student assessment in this framework is not solely the responsibility of the teacher. Assessment is performed by various components of the framework including students, parents, guardians or mentors, artificial agents and/or artificial tutors. Learning environments based on this framework can implement a subset of its components according to their needs.

3. The Learning Game

The Learning Game is a learning environment based on inspectable student models. Participants in this game collect points by working on different learning activities that suggest the use of interactive student modelling tools. Learning activities are personalized and stored on a deck of learning activity cards. Each learning activity includes information such as number of points, tools to use, participants that will accompany the student in this activity (i.e. a teacher, a team member or an artificial guiding agent), time allocated, and a general description of the learning activity. Participants form part of a team (e.g. their home university team) that competes against a simulated rival team (e.g. the home team at a rival university).

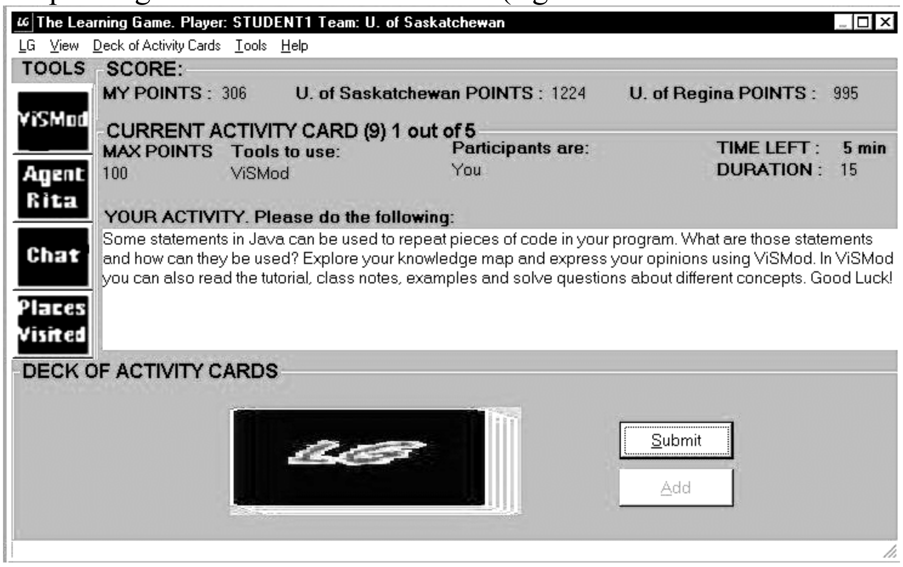

Figure 1. A screenshot of *The Learning Game*. In this activity the student should infer that the activity refers to loops (i.e. while, do while and for) in java. Thus, he/she should use ViSMod to explore these concepts. The student will get a maximum of 100 points when he/she finishes exploring the model

Figure 1 shows a screenshot of *The Learning Game*. The bottom frame shows the deck of learning activity cards, the middle frame depicts the current learning activity and the top frame presents the score. A group of available tools appear on the left of the screen. These tools include an inspectable student modelling tool (ViSMod), an artificial guiding agent (Doña Rita), a chat tool and an interface that shows previously visited concepts the current position of each of the team members (places visited). Using ViSMod students and teachers interact with Bayesian student models. The Bayesian student model includes information about knowledge and social aspects of the student [16]. Bayesian student models are overlaid with the information of a particular student. ViSMod provides special interfaces used by students and teachers to update their own view of the Bayesian student model (i.e. changing the level of knowledge, adding explanations and examples about the student knowledge on various concepts of the student model, self-assessment statements and agreeing or disagreeing with other views of the student model).

3. A Taxonomy of Reflective Actions

Reflection has been defined in different ways by several authors. For example, Brockbank & McGill [5] define reflection as a process by which an experience is brought into consideration in order to derive meaning and conceptualisation and to relate to a particular situation from a different perspective. Hatcher & Bringle [12] state that reflection gives the students the opportunity to gain further understanding of the domain and to develop self-assessment skills. Dewey [1933] defines reflection as a cognitive activity that starts with perplexity, is active, persistent, considers any belief or knowledge, includes a responsibility for future consequences, and is both retrospective and progressive.

Gustafson & Bennet [11] identify a list of factors that affect the degree to which reflection occurs. These factors include characteristics of the learner, environmental factors, and characteristics of the reflective task. Thus, assessing student reflection could result in various degrees of reflection. Bradley [4] presents three general levels of reflection. In the first level, observations are focused on one aspect of the situation. Evidence presented in this kind of reflection is limited to unsupported beliefs. In the second level, the viewpoint is well supported. Observations are thorough. Finally, in the third level, views from multiple perspectives are provided. Conflicting goals are analysed and the situation is explained in terms of a broader context.

These definitions and ideas show that reflection could be supported by creating an appropriate learning environment(s) in which students can gain further understanding of the domain while developing self-assessment skills. These learning environments should encourage students' interaction with the domain in various ways in order to explore different perspectives and incorporate their own experience into the learning process. In fact, learning environments based on ISMs could be used as tools to encourage student reflection. ISMs offer to students and other actors in the learning process (i.e. teachers, classmates, parents or guardians) the possibility to interact with a representation of the student. This interaction can be any meaningful activity that involves asking questions, exploring the model, explaining and/or defending opinions, and learning about him/herself, about the content, or about other students.

Supporting reflection using ISMs requires not only the creation of appropriate graphical interfaces to facilitate learner interaction with the student model, but also it is necessary to offer guidance mechanisms to support the student and enhance reflection while using the student model. In order to analyse student reflection in *The Learning Game*, we have defined an initial taxonomy of reflective actions that includes not only the kinds of student interactions within the game, but also the quality of the explanations provided. In this taxonomy different degrees of reflection (i.e. weak, weak- medium, medium, medium-strong, and strong) are associated with students' behaviours or actions within the system. For example, given a learning activity that refers to a particular concept, students can interact with the student model in a variety of ways (i.e. a student could locate the concept and just read about it while another student could locate the concept, change his/her level of knowledge, explain what he/she knows about the concept, provide several examples, and/or discuss the concept with the teacher or a peer). In fact, based on how the student interacts with the graphical representation of the student model and the information gathered by the system, it is possible to infer different degrees of student reflection in the context *of The Learning Game*.

Table 1 presents a summary of the list of reflective actions and their correspondent degree of reflection for *The Learning Game*. This taxonomy includes aspects such as navigation behaviour and quality of the interactions These reflective actions were refined using the results of a pilot test session of *The Learning Game*. Although degrees of reflection and reflective actions in this taxonomy have been defined to be used in a controlled experiment using *The Learning Game*, this taxonomy can be considered as an initial step towards a more refined and general taxonomy that could be used for analysing student reflection in learning environments that offer graphical representations of the student knowledge or the domain content.

Table 1. Taxonomy of reflective actions for *The Learning Game*

Reflective actions	***Degree of reflection***
Visiting a concept for the first time	
Locating a concept.	**Weak.** The student explores a concept that does not belong to the list of concepts associated to the learning activity. **Weak-Medium.** The student explores a concept that belongs to the list of concepts associated to the learning activity. It reflects that the student has understood the description of the activity and he/she is exploring the appropriate concept nodes.
Locating a concept and reading about it.	**Weak-Medium.** The student uses the tutorial to read about a particular concept.
Locating a concept and changing the student's opinion.	**Weak** • The student states that he/she agrees or disagrees with the system but does not give an adequate explanation. • The student changes the level of knowledge but he/she fails to explain why. **Weak-Medium** • The student only states that he/she agrees or disagrees with the system and provides an appropriate explanation. • The student tells the system what he/she knows about the concept but the explanation provided is a simple reference to the tutorial or is weak. • The student changes the level of knowledge but the explanation provided is a simple reference to the tutorial or is weak. • The student expresses that he/she is interested in the topic, states that that he/she has done research (asked/read) about the topic, or states that he/she has demonstrated his/her knowledge about the concept through tests and/or projects. **Medium.** The student tells the system what he/she knows about the concept. The student provides an appropriate explanation using his/her own words. **Medium-Strong.** The student tells the system what he/she knows about the concept. The explanation provided by the student is complete. It provides examples and additional important information.
Revisiting a concept	
Locating a concept and changing the student's opinion.	**Weak** The student revisits a concept. He/she reads his/her own opinion and the system's/teacher's one. The student does not change his/her opinion. **Weak-Medium, Medium, Medium-Strong, Strong** The student revisits a concept and changes his/her opinion. Since changing the student's opinion could result in different degrees of reflection (see previous reflective action), the resulting degree of reflection for this action the one resulting from changing the student's opinion increased by one.
Other actions	
Seeking confirmation from peers.	**Medium.** The student uses the chat tool to ask a peer for confirmation about a concept.
Visiting random concepts.	**Weak.** The student explores the model randomly.
Visiting concepts suggested by an artificial guiding agent	**Weak.** The student explores the concepts suggested by the agent.
Visiting related concepts (neighbours).	**Weak-Medium.** The student explores neighbour concepts.
Traversing the model hierarchically.	**Medium.** The student explores the model hierarchically.

4. Study Design

We have carried out a study using *The Learning Game* to explore the following two primary questions: how accurate are the student models used in *The Learning Game*? And is there evidence of student reflection? In this paper, we present results related to the second question on student reflection. Although due to the nature of the learning activities in *The Learning Game* and assuming that participants follow the game properly, some of the reflective actions will be in fact observed. However, it is interesting to analyse the distribution of different kinds of student reflection (degrees of student reflection) during the game. Hence, several secondary questions have been derived from this initial question such as:

- What kinds of reflection appear in the course of the student interaction with *The Learning Game*?
- Do different types of learning activities result in different kinds of reflection?

4.1 Methodology

4.1.1 Participants

Participants in this study included fifteen students from CMPT 111 Introduction to Computer Science, two teachers, one observer, one research assistant (wizard), and three human experts. Students were divided into four groups (three groups of 4 students and one group of three) and each group occupied one session. Each session was two hours long.

Students' activities included: completing a pre-assessment quiz, attending to a short training session, playing *The Learning Game*, completing a post-assessment quiz, and participating in a final semi-structured interview. Teachers' activities included: administering a pre- and also a post-assessment quiz, explaining *The Learning Game* to the students during a short training session, negotiating the student model when students ask for it, and interviewing students. The observer took notes of student reactions while they were interacting with *The Learning Game*. In addition, the observer served as technical support person during the study. A research assistant (Wizard of Oz) operated a simple diagnoser system to update the system's view of the student model based on observed evidence. This wizard provided some textual feedback to the student about changes he made to the model.

Teachers, observer, and wizard repeated their performances with each of the four groups of students. After the fact, human experts created (by hand) their own models of each student using information gathered during the study, such as: results from the pre-assessment quiz, student explanations added to the model (except knowledge values), and information gathered by the system (i.e. log information regarding exploration of learning resources, and interactions with team members or teachers about a particular concept).

4.1.2 Domain

The domain was object-oriented programming in java. An initial general Bayesian student model for this domain was created. This Bayesian student model included 54 concepts interconnected in a prerequisite and concept hierarchy structure. Two observable nodes (the system's/teacher's opinion and the student's opinion) were associated with every concept. One node representing social aspects of learning (general aspects of learning) was linked to every concept as well. The Bayesian student model had a total of 163 nodes.

4.1.3 Procedure

This study had five main phases: Pre-assessment Phase, Training Phase, Playing *The Learning Game* Phase, Final Assessment Phase, and the Expert Evaluation Phase.

Pre-assessment Phase (7 minutes). In this phase students solved an initial pre-assessment quiz (i.e. five questions). The results of the quiz were used to generate initial

Bayesian models adapted to the level of knowledge of each student. This was done by the research assistant while the students attended a training session offered by a teacher. This initial model evolves through human and system interaction with different views of the model during the game. *Training Phase (15 minutes).* During this phase a teacher presented *The Learning Game* to the students. This included information about goals of the game, the role of the student, playing *The Learning Game* as part of a team, and different kinds of learning activities.

Playing The Learning Game Phase (75 minutes). Using initially adapted Bayesian student models, students played *The Learning Game* in teams. Each student played *The Learning Game* on his/her own computer. Students represented the U of Saskatchewan team which competed against the U of Regina (computer simulated players). Students worked on five learning activities (i.e. individual, with a peer, with a teacher, and with a guiding agent on different concepts) per session. Learning activities performed by students appear on top of the deck of activity cards and are selected one by one.

Final Assessment Phase (23 minutes). In this phase students solved a post-assessment quiz and were interviewed.

Expert Evaluation Phase. In a separate session, experts created their own models of each student using information gathered during the study. Experts followed comprehensive, detailed traces of student actions.

5. Results

5.1 What kinds of reflection appear in the course of the student interaction with The Learning Game?

Information from the final Bayesian student models and logs was used to determine the number of occurrences of each of the reflective actions in the taxonomy presented in Section 3. Based on this information, it was found that there is evidence of different degrees of student reflection in *The Learning Game*.

Figure 2 shows a summary of the different kinds of student reflection found in this study. Occurrences are grouped in five categories corresponding to different degrees of student reflection. Except for the first two categories (i.e. weak and weak-medium), the number of occurrences decreases as the degree of student reflection increases (i.e. medium, medium-strong, and strong). The number of occurrences in those categories with high degrees of student reflection (medium, medium-strong, and strong) corresponds to 31% of the total analysed while the number of occurrences in categories with low degrees of student reflection (weak and weak-medium) corresponds to 69%.

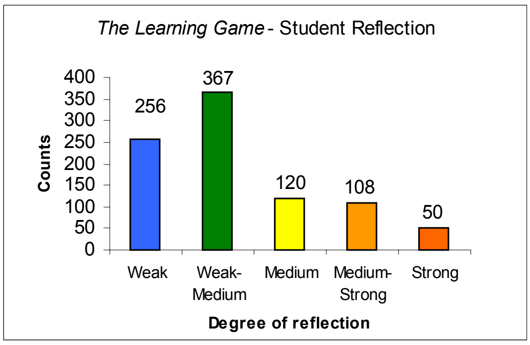

Figure 2. Student reflection in *The Learning Game* (number of occurrences)

Variations on student reflection are explained by the nature of student interactions with *The Learning Game*. The quality of the interaction depends on the number of times the student revisits a particular concept and the feedback the student has received. It is through interaction that explanations become more refined. Such explanations are associated with higher degrees of student reflection. For example, in many cases, students started with a simple description of a concept but added more information and examples during the game.

5.2 Do different types of learning activities result in different kinds of reflection?

Learning activities in *The Learning Game* are associated with different kinds of assessments. There are individual activities (self-assessment), interacting with a team member or an artificial guiding agent (collaborative assessment), and negotiating the student model with a teacher (negotiated assessment.) Thus, in this question we address the effects of different kinds of assessments on student reflection.

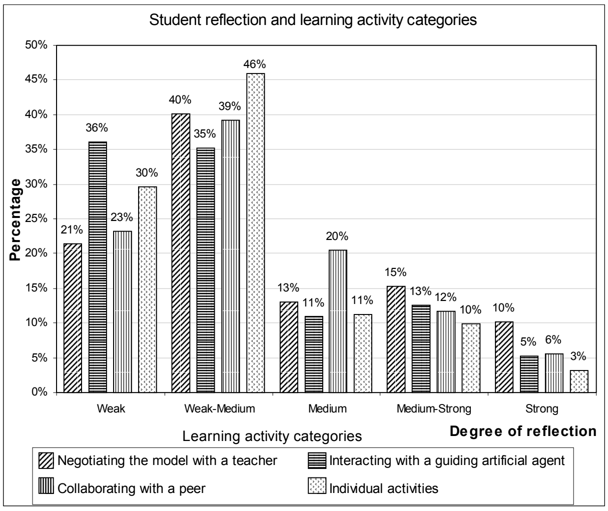

Figure 3. Distribution of the occurrences found on each of the four learning activity categories over each of the five categories of student reflection

Student interactions with *The Learning Game* were grouped into four learning activity categories. Figures 3 shows how occurrences found on each of the four learning activity categories are distributed over each of the five categories of student reflection. For example, when the student negotiated the student model with a teacher, 21% of the interactions were classified as weak, 40% as weak-medium, 13% as medium, 15% as medium-strong, and 10% as strong. Although only 31% of the interactions analysed belong to categories with high degrees of reflection (medium, medium-strong, and strong), there is a noticeable variation of the distribution of the occurrences on each of these categories. For instance, strong student reflection represents only 3% of the total on the individual category while it reaches a 10% when working with a teacher. The other two learning activity categories show percentages of strong student reflection that fall between these levels (i.e. 5% when interacting with an artificial agent and 6% when interacting with a human peer.) Similar percentages are found when analysing the categories with high degrees of student reflection as a single unit (24% individual activities, 29% interacting with an agent, 38% interacting with a peer, and 38% negotiating the student model with a teacher.)

These results show that for a fixed period of time, the number of occurrences in the categories with high degrees of student reflection is greater when the student is not alone. In addition, high degrees of student reflection are associated with more sophisticated interaction mechanisms (i.e. interacting with a teacher.) In fact, based on the taxonomy of reflective actions, high degrees of student reflection can be achieved by revisiting concepts and improving the quality of students' interactions.

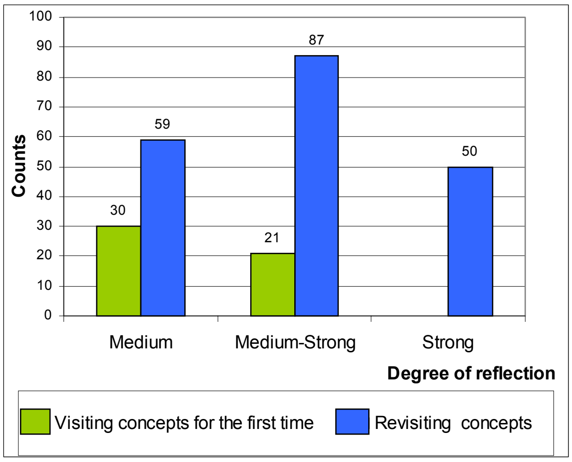

Figure 4. High degrees of student reflection

Figure 4 shows that when visiting a concept for the first time, the number of occurrences in the categories with high degrees of student reflection become less frequent as the level of reflection increases. However, when students revisited concepts and there is feedback available of some sort, high levels of student reflection present values over 50 (number of occurrences). Values on this figure correspond to the total of observed interactions in the categories medium-strong (108) and strong (50) and to 74.2% of the total of interactions with a medium degree of student reflection (89 out of 120). The rest 31 interactions in the medium category correspond to seeking for peer confirmation (24) and traversing the model hierarchically (7).

In addition, providing feedback plays an important role on reaching high degrees of student reflection. Results show that 78.6% of the interactions observed when students revisited concepts belong to learning activities in which students interacted with a peer (17.9%), with a teacher (30.1%) or with an artificial agent (30.6%). Even when interacting with the student model individually (the rest 21.4%), students received some feedback from the system.

Hence, revisiting concepts and providing feedback to students seem to be two important factors in achieving high degrees of student reflection. Some of the learning activities in *The Learning Game* were presented to students only when initial evidence for the concept or concepts to be explored was available. When interacting with a teacher, for example, teachers and students focused their discussion of those concepts previously explored by the student. Similarly, the artificial guiding agent pointed out to the student concepts with conflicting evidence, that is, previously explored concepts where the system and the students seemed to disagree. These learning activities encourage revisiting concepts and refining of students' opinions while offering feedback. The results show that student interactions in these activities showed a greater tendency toward more highly reflective acts.

Providing appropriate feedback has been identified as an important factor in promoting reflection. This study shows that different degrees of student reflection can be inferred when students interact with learning environments based on inspectable student models. Even when working individually, their interactions with the student model showed the presence of student reflection. Although offering immediate human-like feedback would be ideal, it is certainly not the only strategy that could work in these kinds of learning environments.

5.3 Other observations - Navigating through the model

Some reflection actions regard student navigation behaviour such as traversing the student model hierarchically, exploring random concepts, exploring related concepts (neighbours), exploring concepts that belong to the list of concepts associated with the learning activity, exploring concepts that do not belong to the list, exploring concepts suggested by the agent, and being prompted by the student model to engage in tutorial activities.

Results showed that hierarchical navigation (i.e. traversing three or more levels of the student model) was only observed when students interacted with the teacher (7 observed interactions). Visiting related concepts (neighbours) was present in all of the learning activity categories (41 individually, 21 with a peer, and 31 with a teacher and with the agent).

For learning activities involving a peer or a teacher, students explored the concepts associated with the learning activity more than other concepts. For individual learning activities there was not a marked preference. Students exploring the model individually navigated more than in any other learning activity. Students used the tutorial quite frequently, especially in individual activities and when interacting with the guiding agent (an average of 34 observed interactions). Finally, students consistently followed the directions of the guiding agent (79 observed instances).

6. Conclusions

This study has shown the presence of student reflection in *The Learning Game.* Guided interaction with the student model is a key factor that contributes to promote student reflection. In fact, high degrees of student reflection were found when students revisited concepts and received feedback. It is interesting that learning activities such as interacting with an artificial guiding agent are shown to be effective in promoting high degrees of student reflection. This result shows that it is possible to develop computer-based strategies to support high degrees of student reflection.

The Learning Game as a learning environment based on ISMs was successful in motivating and supporting student interaction with the student model. *The Learning Game* offers tools to interact with the student model, mechanisms to integrate and propagate evidence and feedback of different sorts.

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