Usage Scenarios and Evaluation of Teacher Assistance Tools for Exploratory Learning Environments

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Abstract

One of the main obstacles to the integration of exploratory learning environments (ELEs) in the classroom, in spite of their benefits in terms of student engangement and long-term learning, is teachers' perceived lack of control. There is a clear need to provide teachers with tools that enhance their awareness of the classroom state and give them control over their students' learning activities. This paper discusses teachers' requirements for such tools in the context of an ELE supporting the learning of algebraic generalisation and describes our iterative approach to designing, developing and evaluating the tools in collaboration with teachers. The paper describes the design and outcomes of formative and summative evaluations undertaken with the tools. We draw conclusions relating to the value of the tools to teachers and their possible extensions to other learning domains.

Keywords: teacher support, iterative design, intelligent support, exploratory learning environments

1. Introduction

Exploratory Learning Environments (ELEs) are a particular type of learning environment where the focus is on students' exploration of the knowledge domain. Examples of ELEs include simulators, virtual labs, microworlds, and

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educational games. ELEs give considerable freedom to students, who may explore and learn in a variety of different ways. The tasks that students are asked to undertake are open-ended in nature, may have many alternative solutions, and encourage students to explore the learning environment and to follow a variety of solution approaches. Research has found that considerable guidance is required to ensure learning in such open-ended contexts (Kirscher et al., 2006; Kynigos, 1992; Mayer, 2004), but that in the presence of adequate support ELEs can lead to more engagement and deeper learning (see (Noss and Hoyles, 1996; de van Jong and Joolingen, 1998) and, for more recent reviews of the area, (Joolingen and Zacharia, 2009; Healy and Kynigos, 2010)).

In order to provide immediate support to students as they are interacting with an ELE, recent efforts aim to design intelligent components that undertake at least some of the simple aspects of providing feedback to students (Gutierrez-Santos et al., in press; Amershi and Conati, 2009). However, this intelligent support cannot completely replace the teacher whose role in an exploratory learning setting is that of a 'facilitator', or 'orchestrator' (Trouche, 2004; Hoyles et al., 2004). This role would be relatively easy in one-to-one student-tutor interaction, but scaling it up to the number of students in a typical classroom poses several challenges, that are further compounded by the use technology. Given the open-ended nature of the tasks that the students are working on, teachers can only be aware of what a small number of students are doing at any one time as they walk around the classroom. The computer screens of students who are not in their immediate vicinity are typically not visible to them and these students may not be engaged in productive construction (going so far, in our own experience, as browsing the web, playing games, or engaging in online chat). It is therefore hard for teachers to know which students are making progress, which are off-task, and which are in difficulty and in need of additional support. Even for these students whose screens are currently visible to the teacher, it may be hard for her to understand the process by which students have arrived at the current state of their construction and the recent feedback they have received from the system, and to provide appropriate guidance.

In this paper we present our approach to designing tools that can assist teachers in a classroom where students are using an ELE. Our case study is an intelligent microworld designed to support 11-14 year old students' development of algebraic ways of thinking. We have designed a suite of visualisation and notification tools, which we refer to as the *Teacher Assistance*

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(TA) tools. The aim of these tools is to assist teachers in focussing their attention across the whole class as students are working with the microworld, and to inform teachers' own interventions in supporting students to reflect on their work, on the feedback given them by the microworld and in setting and working towards new goals.

In (Pearce-Lazard et al., 2010; Gutierrez-Santos et al., 2012) we described the architectural design and implementation of the TA tools, focussing specifically on one tool, the Student Tracking (ST) tool (see Sections 2 and 4 below). In contrast, the present paper discusses the pedagogical rationale for the TA tools, the teachers' requirements from such tools, and the methodological approaches we have followed in developing them. We identify the main usage scenarios of the TA tools and discuss the design and results of a series of formative and summative evaluation activities (these have only recently been completed and so were not reported in (Pearce-Lazard et al., 2010; Gutierrez-Santos et al., 2012)). Also, the discussion in the present paper encompasses the whole suite of TA tools targeted at supporting the teacher in monitoring students' activities and progress in the classroom.

The outline of the paper is as follows. In Section 2 we give an overview of the context and functionalities of our system, and of related work in the areas of exploratory learning environments and support for the teacher. In Section 3 we discuss the methodology we have adopted in designing, developing and evaluating the TA tools. We also discuss teachers' requirements from the tools, in the form of a set of usage scenarios. In Section 4 we describe the tools themselves — the Classroom Dynamics (CD), Goal Achievements (GA) and Student Tracking (ST) tools. Section 5 discusses the formative evaluation of the tools with teachers and teacher educators, and changes that were made to them as a result. Section 6 presents the results from a set of summative evaluation activities with the tools. Section 7 discusses the outcomes of these evaluations. Section 8 gives our concluding remarks and directions for further research.

2. Background and Related Work

In sub-section 2.1 we present the MiGen system context in order to help the reader understand our particular case study and to provide a glimpse of the open-ended nature of the activities that students undertake. In sub-section 2.2 we present related work.

2.1. The MiGen system

The MiGen project (http://www.migen.org) has designed and developed an intelligent, exploratory environment to support 11 to 14-year-old students learning of algebraic generalisation. Using a mathematical microworld called the *eXpresser*, students are asked to construct two-dimensional tiled models and associated algebraic rules. In order to build their model, students need to create 'building blocks' out of unit-square coloured tiles depending on their perception of the model's structure, and to repeat each building block in order to form a 'pattern' which forms part of their overall model. The algebraic rules they are asked to construct relate to the number of tiles of each colour required to paint each pattern and their model overall. Each building block is made up of a group of tiles, and can be repeated horizontally, vertically or diagonally to contribute to the construction of a 'pattern'. For example, Figure 1 shows an example model that students may be asked to construct. They may do so by creating building blocks to generate the centres of the flowers, the petals, and the stalks, that they will then repeat to make the yellow, red and green patterns, respectively. They will be nudged towards deriving rules for the number of red tiles and the number of green tiles required to paint their model for a given number of yellow tiles.
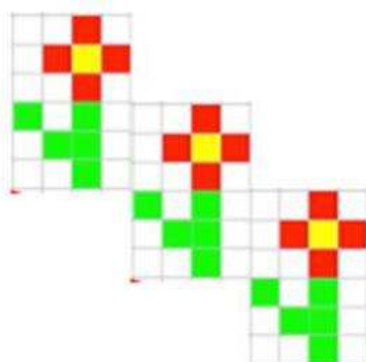

Figure 1: An example model that students may be asked to construct in eXpresser

Students are prompted by the eXpresser to check that their models and rules are *general*, which they can accomplish by making appropriate use of variables. For example, constructing the model in Figure 1 requires one variable — for the number of yellow tiles. If the model has been constructed generally by the student, changing the value of this variable will lead to the whole model being updated correctly and also still being correctly and fully

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coloured. The eXpresser has an 'animation' facility which allows students to explore the generality of their models and rules. This facility automatically applies different random values to the variables used by the student and displays the resulting instances of the model in a separate pane of their screen.

Tasks are designed to contextualise students' interaction with the eXpresser and include a set of goals that students need to achieve, e.g. 'construct your model', 'make sure it is correctly coloured', 'check that it animates without messing up', 'check that your animated model is always correctly coloured'. The task goals are presented to the student within an *Activity Document*, in which students can tick off goals they believe they have completed, answer questions relating to the task, and reflect on their construction approach. We refer the reader to (Manolis et al., 2012) for further details of the eXpresser, its 'epistemic affordances' and how it can enhance students' understanding of algebraic generalisation and to (Noss et al., 2012) for further details of the MiGen system architecture, the Activity and Task design tools, and Activity Documents.

Exploratory Learning Environments such as MiGen's eXpresser have the potential to support students' exploration while at the same time fostering progressive building of knowledge. However, the exploratory nature of the tasks undertaken with eXpresser requires that personalised feedback is provided to students as they construct their solutions, and not just at the end of the task. This feedback includes prompts to help students engage with a task, guide them towards successful completion of the task, and generalise their solutions (Noss et al., 2012; Gutierrez-Santos et al., in press). This feedback is generated by another component of the MiGen system, the *eGeneraliser*, based on analysis of students' actions in the eXpresser. The aim of the feedback is to balance students' freedom to explore while at the same time providing sufficient support to ensure that learning is being achieved. We refer the reader to (Gutierrez-Santos et al., in press) for details of the design of the eGeneraliser and of the feedback that it provides to students.

As students are undertaking the task set in the eXpresser, a series of *indicators* are automatically detected by the eXpresser or inferred by the eGeneraliser and submitted by them to the MiGen Server for storage in the MiGen database[1]. The set of indicators that are meaningful and useful for

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[1]The MiGen software comprises the eXpresser running on each student's computer,

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teachers in their role in the classroom has been identified through an iterative process, undertaken collaboratively with our group of teacher collaborators on the MiGen project (see Section 3).

There are two categories of indicators: Task Independent (TI) indicators refer to aspects of the student's interaction that are related to the microworld itself and do not depend on the specific task the student is working on. TI indicators generally refer to a single action undertaken by the student, such as 'placed a tile on the canvas', 'created a building block', 'created a pattern'. In contrast, the detection of Task Dependent (TD) indicators requires knowledge of the task the student is working on, may relate to combinations of student actions, and requires intelligent reasoning by the system. This reasoning is undertaken by the eGeneraliser, using a mixture of case-based and rule-based techniques. Examples of TD indicators are 'student has made a plausible building block for this task', 'student has coloured their pattern generally' and 'student has achieved a task goal'. Detailed discussions of the MiGen's TI and TD indicators and how the latter are inferred by the eGeneraliser may be found in (Gutierrez-Santos et al., 2012).

The TA Tools, which we describe in Section 4, receive real-time information from the MiGen server relating to occurrences of TI and TD indicators for each student, and each TA tool presents a selection of this information in a visual fashion to the teacher.

2.2. Related Work

To our knowledge, MiGen's TA tools represent the first work — preliminary results were published in (Pearce-Lazard et al., 2010) — targeted at notifying teachers of students' progress and state during exploratory learning activities in the classroom, notifying the teacher of students' attainment of key indicators, and aiming to inform the teacher's own interventions in the class. This novelty of our TA tools has presented a number of methodological challenges, which we discuss in Section 3. In the last two years, several similar initiatives have appeared, including the recent approach of (Gutiérrez Rojas et al., 2012) —inspired by early work in (Yardi, 2008)— that focuses on informing teachers of students' progress and need for help in the context of

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the TA tools running on the teacher's computer, and the MiGen Server and database running on a third computer. The MiGen database stores all the information produced and required by the eXpresser and the TA tools (see (Noss et al., 2012; Gutierrez-Santos et al., 2012) for details).

computer programing labs. Earlier work (e.g. (Gueraud et al., 2009)) focuses mostly on the statistics of the interaction (e.g. how often did the student produce a certain kind of indicator). As we discuss in the present paper, our requirements analysis with teachers showed that immediate on-line feedback about students' current status and progress is more valuable to the teacher than simple statistics in supporting the 'orchestration' of students' use of technologies in the classroom.

The trend towards teacher support is recently growing also in the learning analytics community (see for example (Garcia et al., 2012; Zaldivar et al., 2012; Pardo, 2012)) and there is high synergetic potential between that work and the work reported here. Other related initiatives include using Web log data generated by course management systems (e.g. WebCT) to help instructors become aware of students' activities in distance learning classes (Mazza and Dimitrova, 2007); post-analysis of the system's data logs for helping teachers understand students' behaviour in adaptive tutorials (Ben-Naim et al., 2008); and providing awareness information to teachers so as to support their role as moderators of multiple e-discussions (Wichmann et al., 2009) or class-wide collaborative activities supported by hand-held devices (Cortez et al., 2009). Particularly interesting is the work described in (Voyiatzaki et al., 2008), that uses tools to analyse CSCL synchronous interaction to help the teacher; their use of "rules" to find specific landmarks in the interaction bears some similarity to our detection of interaction indicators. However, none of this work focuses on exploratory learning activities specifically.

3. Methodology

In our experience, teachers are not used to having access to tools such as MiGen's TA tools, and their normal instinct is to walk round the classroom in order to monitor how individual students are progressing and to help them. As discussed earlier, this approach has significant limitations in an exploratory learning setting due to the difficulty for the teacher to keep track of how a whole class of students are progressing, each at their individual pace and using their own construction approach to the task at hand. Because of teachers' general lack of experience with tools such as MiGen's TA tools, it was not possible for us to elicit from the outset a set of requirements for these tools from our teacher collaborators. Instead, it has been necessary to adopt an iterative methodology comprising successive phases of prototyping, requirements elicitation, incremental development and evaluation, in

collaboration with teachers.

Our Teacher Advisory group on the MiGen project comprised around 20 maths teachers and mathematics educators from a broad spectrum of secondary schools in the greater London area, who attended regular project team meetings and gave their input to this process. However, the time that these teachers had available to use early prototypes of the tools in their classrooms was limited, and collaboration with a core group of 4 teachers played a prominent role in this respect.

Phase A. After a first version of the eXpresser and of the student feedback provided by the eGeneraliser had been developed during the first 15 months of the project, we undertook a first phase of prototyping and requirements elicitation for the TA tools, working with our teacher collaborators. Mockups and prototypes of several possible visualisations were developed and discussed in meetings of the Teacher Advisory group and in one-to-one interviews with those teachers who had trialled the eXpresser and eGeneraliser in their classrooms. The aim of these interactions was to elicit teachers' views about what information relating to students' progress would be useful for them to have as students are working on eXpresser tasks, and how they would like this information to be presented. As an outcome of Phase A, two visualisations were developed, which subsequently evolved into the Classroom Dynamics (CD) and Student Tracking (ST) tool (see Section 4 below). Also identified were a preliminary set of TI and TD indicators to be monitored by the system as students are working on the task set and to be presented to the teacher by the ST tool.

Phase B. The next phase of development of the TA tools began with several classroom sessions trialling early prototypes of the ST tool with two teachers in two schools. These early trials are described in (Gutierrez-Santos et al., 2012) and we refer the refer the reader to that paper for details. Following the classroom trials, one-to-one interviews were held with the teachers so as to inform the further development of the TA tools, and to gain insight into how the teacher would use such tools in practice in the classroom. In these interviews, both teachers suggested that rather than having the TA tools installed on the teacher's desktop PC, it would be preferable to install them on a tablet PC; this would allow teachers to view the tools as they are walking around the classroom without having to keep returning back to their desk. This approach was adopted for subsequent classroom trials of the

tools in Phase D. The need for a third tool was also identified, which would show students' incremental achievement of the task goals during the lesson. This resulted in the development of the Goal Achievements (GA) tool (see Section 4). Finally, a set of Usage Scenarios for the whole suite of tools were identified, which we list as US1–US8 in Tables 1 and 2. These usage scenarios informed the development of the CD and GA tools, and the design of the formative and summative evaluations of the whole suite of tools in Phases C and D.

Phase C. This involved formative evaluation of the TA tools, firstly with a group of trainee maths teachers on a Postgraduate Certificate in Education programme at the University of London, and subsequently with a group of pedagogical experts in maths education. We report on the design and outcomes of these evaluation activities in Section 5.

Phase D. The final phase of development of the TA tools involved summative evaluation, undertaken in two parts. In the first part, we conducted two classroom trials, both with the same teacher and the same class of students. In the first, the teacher had access to the TA tools to monitor students' progress and support them as they were working on a task in eXpresser, whereas in the second (held on the next day) the teacher was asked to conduct the lesson without referring to the TA tools. The second part of the summative evaluation was undertaken with a new cohort of trainee maths teachers on the same Postgraduate Certificate in Education programme as in Phase C. We report on the design and outcomes of these summative evaluation activities in Section 6.

4. The Teacher Assistance Tools

As discussed in the previous sections, MiGen's Teacher Assistance (TA) Tools aim to support the teacher in monitoring students' progress on tasks set for them to undertake in eXpresser, so that the teacher can intervene with additional support for the class as a whole or for individual students as she deems appropriate. The most detailed tool, and the one developed first chronologically, is the ST tool. So we begin with a description of that below, followed by the CD tool and the GA tool.

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1	*Finding out which students need the teacher's immediate help.*
	The teacher can consult the CD tool and see which students' circles are coloured Red and how many of the task goals they have achieved. The teacher can click on a student's circle to view their current model and rule, to provide some context for the help to be given to the student. The teacher can also open up the ST tool to view the recent indicators relating to the student's actions, to provide additional context. If there is more than one student coloured Red in the CD display, the teacher may select to help first students who have achieved the fewest task goals.
2	*Finding out which students are progressing satisfactorily towards completing the task and which students may be in difficulty*
	Similarly to US1, the teacher can consult the CD tool to see students in need of help, how many task goals students have achieved, and students' current models and rules; and the ST tool to view students' recent indicators. The teacher can open up the GA tool to view specifically which task goals are being achieved by each student.
3	*Finding out which students are currently disengaged from the task.*
	The teacher can consult the CD tool and see which students' circles are currently coloured Amber. If any of these students has not completed all the task goals, then she/he is likely to be currently disengaged from the task and in need of encouragement from the teacher. If a student has completed all the task goals, then she/he may need to be set additional goals or a new task to work on while waiting for the rest of the class to finish.
4	*Identifying common conceptual and procedural difficulties students are facing in order to provide more explanation to the class as a whole.*
	Consulting the GA tool allows the teacher to see which task goals students are having difficulty completing, so as to inform additional explanation to the class. Consulting the ST tool allows the teacher to see if there are specific Red indicators showing in many of the students' columns, indicating particular procedural difficulties that students may be facing and again informing the provision of additional explanation to the class.

Table 1: Usage Scenarios US1–US4

5	*Finding out which students have finished the task.*
	The CD tool can be used to see which students have achieved all the task goals. For these students, the teacher can click on their circles to view their final model and rule, to check if they have achieved a correct solution. The teacher can then go to each student to set them a new task or additional goals relating to the current task, if their solution was correct; or ask them to reflect further on their construction if not.
6	*Finding out which students have achieved which task goals.*
	The GA tool can be used to see which students have achieved which of the task goals.
7	*Providing appropriate support and guidance to individual students (i) during the lesson, and (ii) after the lesson.*
	This can be undertaken during the lesson using a combination of the tools as described for US1, US2, US3 above, and after the lesson by using the GA tool to see which task goals an individual student has not managed to achieve, the CD tool to view the student's final model and rule as produced by the end of the lesson, and the ST tool to view the student's detailed history of interactions during the lesson.
8	*Reflecting on the class' achievements and planning the next lesson.*
	This can be undertaken using a combination of the GA tool, to see which task goals have been largely achieved by the class, the CD tool to view selected students' models and rules, and the ST tool to see a historical record of how students tackled the task during the lesson.

Table 2: Usage Scenarios US5–US8

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4.1. Student Tracking

The ST tool monitors the occurrence of TI and TD indicators generated by each student as they interact with the eXpresser. These indicators are displayed in chronological order in a top-down timeline for each student (see Figure 2), with one column for each student in the class. Indicators whose occurrence indicates that the actions of the student are consistent with what would be expected from productive interaction with respect to the task at hand are coloured Green; indicators whose occurrence is regarded as an obstruction to productive interaction are coloured Red; indicators whose occurrence indicates that some aspect of the student's interaction may be positive or negative depending on context are coloured Yellow; and indicators relating to feedback given by the system to the student are coloured Blue.

Timelines can be made thinner or wider using a slider. Using narrower timelines provides a general overview of all the students' timelines but does not show the text associated with the indicators. Using wider timelines allows a more detailed exploration of the indicators for a particular student. Timelines can also be made shorter or longer (so that a vertical pixel represents a longer or shorter time period). A shorter view allows the teacher to undertake a general appraisal of all the students' actions so far. A longer view allows the teacher to look in detail at students' interactions during a specific time period. Hovering with the cursor over one of the indicators provides further information: full name of the indicator and precise time it occurred. For some indicators additional information is also shown, e.g. for the indicator relating to the accomplishment of a task goal, the full name of the goal.

Indicators are displayed as horizontal bars or vertical lines depending on whether they are event indicators or state indicators. Event indicators relate to an action that happens at a single time point, e.g. goal accomplished, pattern created, feedback received. State indicators represent an aspect of the students' interaction that is always monitored and has a value of 'yes', 'no' or 'maybe', e.g. 'student is active', 'student is animating their model', 'a plausible building block is in use'. The identification of the full set of indicators was achieved through an iterative process undertaken as a joint activity with our teacher collaborators during Phases A and B of the project. This resulted in the development of computational techniques to track over 50 different indicators. We refer the reader to (Gutierrez-Santos et al., 2012) for a detailed description of the different categories of indicators.

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During the classroom trials in Phase B it became evident that it was infeasible for teachers to comprehend all of this information at one time within the ST tool. Larger combinations of the indicators would be useful for after-class analysis, but the number of indicators to be displayed during the classroom session needed to be reduced. The ST tool was therefore extended to allow the teacher to select which indicators should be shown and which hidden, depending on the teacher's current needs. For convenience, the indicators are divided into a number of 'families' which the teacher can select to be collectively shown or hidden (the teacher can also select individual indicators to be shown/hidden). The families of indicators are: event indicators, state indicators, building-block related indicators, rule-related indicators, and important indicators. This last category of 'important' indicators was identified by a team of pedagogical experts in Phase C of the project as being the most relevant for use by the teacher during the lesson (for reasons of space we do not list them here and we refer the reader to (Gutierrez-Santos et al., 2012) where they are listed).

Figure 2 illustrates the ST tool visualisation, with the important indicators and the 'Tile placed' indicator selected. Looking at the left-most column, we see that student Anne Smith (all students' names are aliases) has placed a tile, but has then been detected as being inactive by the system. The system has displayed an appropriate prompt to the student at this point, and she has resumed placing tiles. The system has detected 'rhythm' from these tile placements — in the sense that the tiles placed on the canvas match part of the target model to be constructed — and has suggested that she create a building block from her tiles, which she has subsequently done. The system detects that this is a plausible building block for the task at hand (shown by the occurrence of the green 'Building Block created' indicator). Anne continues to create a pattern from her building block, and to accomplish the first goal of the task.

4.2. Classroom Dynamics

The CD tool gives the teacher an at-a-glance overview of which students are currently engaged with the task and who may be in difficulty and in need of the teacher's help (see Figure 3, left-hand side). It represents each student in the classroom by a coloured circle, with the student's initials within it. Hovering over a circle with the cursor displays the student's full name. Clicking on a circle shows the student's current construction and current rule (see Figure 3, right-hand side). The colour of a student's circle reflects the
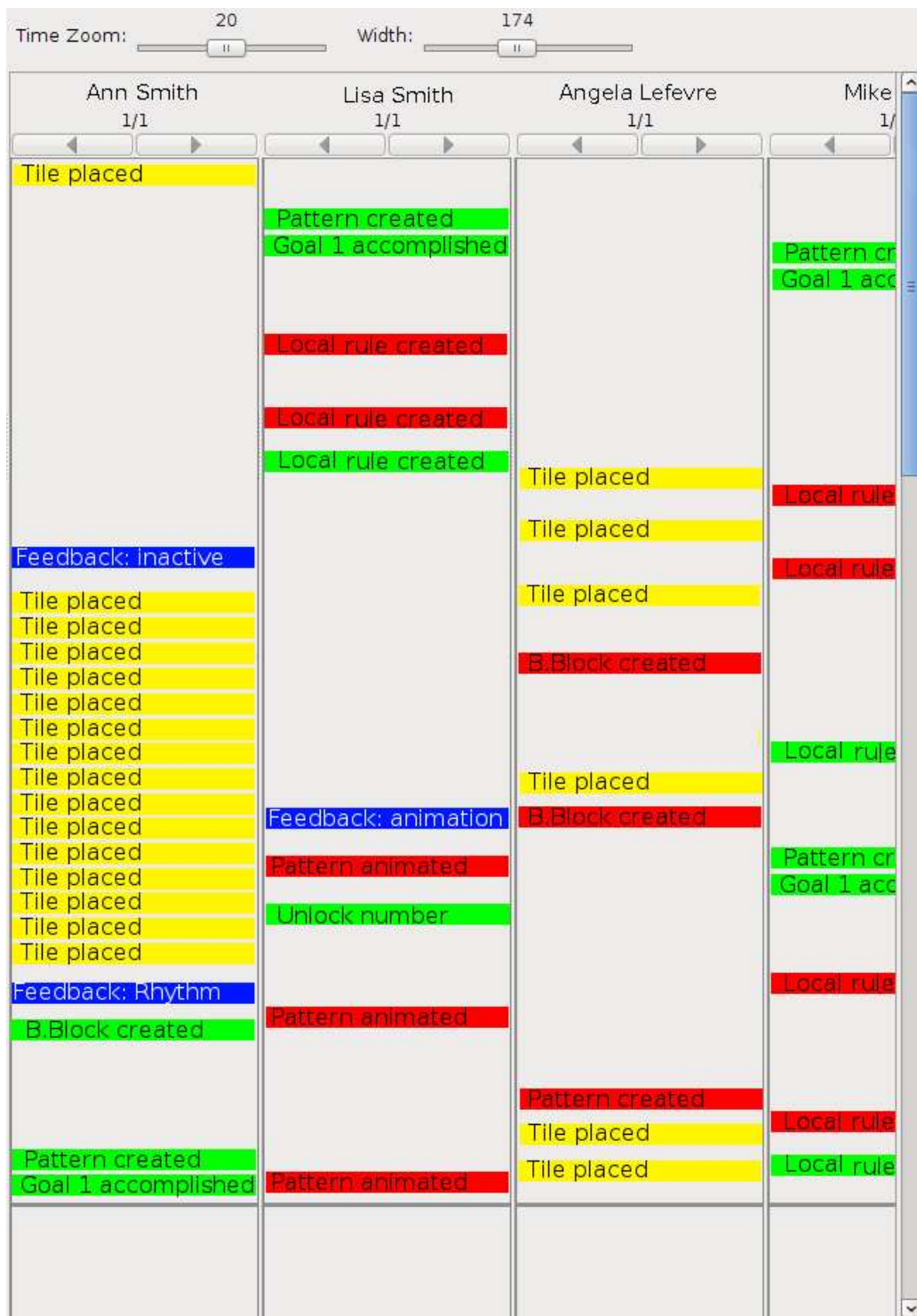
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Figure 2: Student Tracking visualisation. The first column shows how Ann Smith showed little interest in the task at first, but made progress later thanks to support and feedback from the system.

student's current activity status as perceived by the system: students shown in Green are working productively on the task set as far as the system can tell; students shown in Amber have not interacted with the eXpresser for some time (by default, five minutes); students shown in Red have requested help from the system in a situation where the intelligent support cannot help any further: at such times the eXpresser displays the message "The teacher will come to help you now" and the student's circle becomes coloured Red in the CD tool in order to attract the attention of the teacher.
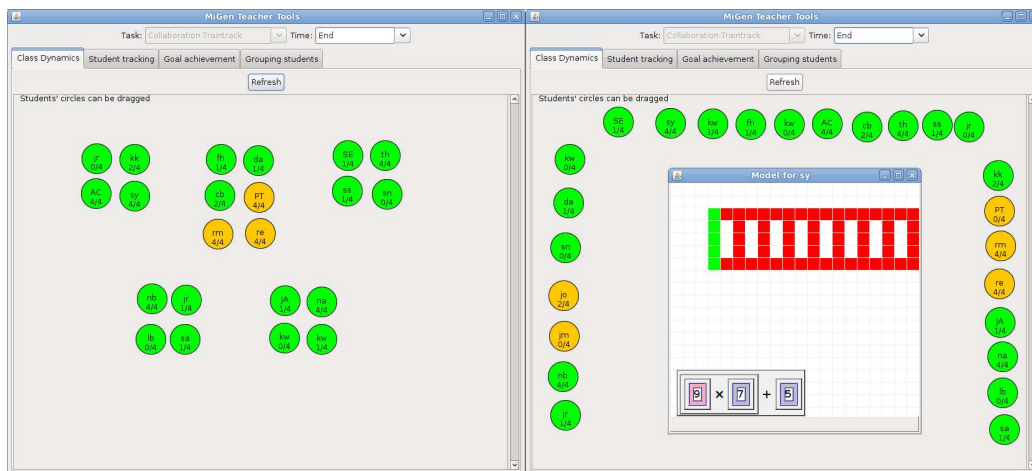

Figure 3: Class Dynamics tool. On the left, a classroom with the students sitting at tables. On the right, another classroom with students sitting at desks by the walls; in this case, the teacher has clicked on one of the students to see their construction and rule.

The circles representing the students can be dragged and moved around on the canvas. This enables teachers to set up the display so that the position of the circles matches the students' spatial positioning in the classroom. This helps the teacher to match the information displayed in the CD tool with her own observations. It also helps the teacher to identify situations that may be location-dependent. For example, if several students seated at the same table show as Amber this may indicate that they are distracting each other and that the teacher should intervene to refocus their attention on the task.

An optional feature in the CD tool shows within each student's circle the number of goals achieved so far, as a fraction of the total number of goals of the task. For example, if a student has achieved two of the goals of a task that has four goals, this would show as 2/4. This does not provide information about *which* of the task goals have been achieved and generally

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task goals can be achieved in different orders. More detailed information about the achievement of task goals is shown by the Goal Achievement tool.
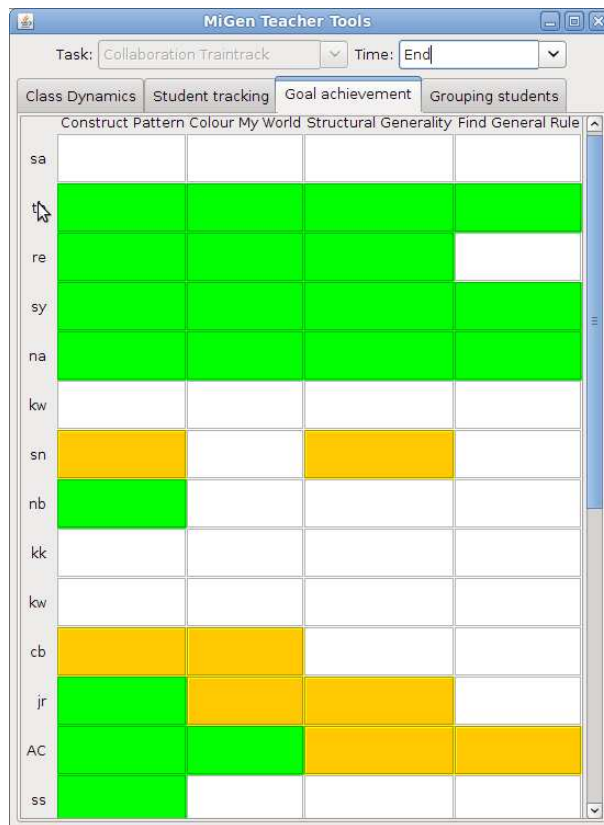
4.3. Goal Achievement

Figure 4: Goal Achievement tool. It can be seen that some students have achieved all or most task goals, some students are not making any progress, and some students are moving back and forth.

The GA tool shows a tabular display of students and task goals (see Figure 4). Each row of the table shows the progress of one student (identified by their initials) in completing the task goals. Each column shows the completion status of one task goal for all students. The names of the tasks are shown at the top and the bottom of the columns. Each student has several cells next to their name, one cell for each task goal. Hovering over a cell with the cursor displays a full description of the goal, the name of the student

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and the achievement status of that goal for that student. We note that the goal achievement information displayed by the GA tool is inferred by the eGeneraliser and may not necessarily correspond to the information about goal achievement provided by the students themselves in their Activity Document: sometimes students tick as 'done' task goals they believe they have achieved but which the system infers as not actually being achieved; conversely, sometimes students do not tick as 'done' task goals (e.g. they forget) that the system infers as being achieved.

The GA tool uses colour coding to identify the current status of a task goal for each student: a White cell shows that a goal has not been achieved yet; a Green cell shows that the goal is currently being achieved by the student's construction; an Amber cell shows that the goal has been achieved by the student during the course of the current task, but is not being achieved by the student's current construction. A task goal can appear as Amber for several reasons. For example, some students may finish the task earlier than others and the system gives such students the opportunity to undertake the task again but this time following a different construction approach; such students would appear with all their task goal cells coloured Amber in the GA tool and with the cells gradually turning to Green again. Some students may not recognise that they have accomplished a task goal and their further interaction with eXpresser may result in a situation where the goal is no longer being achieved, either accidentally (e.g. a pattern was coloured generally but then a variable is deleted) or in an explicit attempt to achieve some other task goal (e.g. in order to relate two patterns via the same variable, the student may temporarily leave them uncoloured). Using three colours for visualising the task goal achievement information allows the teacher to differentiate between those students who have moved back and forth taking different construction approaches to the task and those students who are having problems completing the task and cannot advance.

4.4. Time-stop Functionality

This is a cross-tool functionality provided by all the TA tools. It allows the user to select a specific point in time, t, with respect to which the ST, CD and GA visualisations are generated. The tools ignore all indicator occurrences after that time point, allowing analysis of the situation at that particular time. In particular, the ST tool shows the history of indicator occurrences for all students up to time t, the CD tool shows the classroom status at time t, and the GA tool shows the goal achievement information at time t. If the

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time point selected is in the future, or if no time point is explicitly selected, the tools show the current situation by default.

The time-stop functionality has several important uses. Firstly, it allows teachers to see information relating to a point in time in the past in order to better understand the context of a particular situation. For example, using the ST tool after the lesson, the teacher may observe an unexpected sequence of indicators for a student. The teacher can use the CD tool 'frozen' at that particular moment to check what was the status of other students nearby, e.g. were they all inactive/in need of help? Secondly, the time-stop functionality allows the TA tools to be used by the research team to visualise —for research purposes— the students' interaction data arising from each classroom session. Thirdly, being able to use the interaction data gathered from classroom trials and to present that data via the TA tools 'frozen'at particular moments in time enables the evaluation of the TA tools with a far larger number of teachers than those who are able to participate in classroom trials, allowing the research team to pose questions to evaluation participants as if they were in the real classroom at that precise moment.

4.5. Example of Use of the TA tools

In order to facilitate readers' understanding of the TA tools, we now briefly describe how they may be used in a typical classroom session. At the start of the session, the teacher introduces the lesson and instructs students to open the eXpresser on their computers and to read about the current task within the Activity Document. While they are doing this, she opens up the TA tools on her computer, typically a tablet. For the first few minutes of the lesson, the teacher walks around the classroom to make sure that students are focussing on the task at hand and that they understand the task goals. Once students have begun working on the task in eXpresser, the teacher can take a step back and use the TA tools to monitor students' progress.

Most of the time, the teacher will have the CD tool selected for display. If any students show as amber, she approaches them and encourages them to resume working on the task. Some students may call out to the teacher for help, or may raise their hands. The teacher encourages them to first seek help from the system: "If the system cannot help you, then I will come to you" she tells them, knowing that students in such a situation will automatically appear red in the CD tool. If a student does appear red, the teacher goes to the student to help, since she knows that this is a situation where the system's intelligent support cannot help the student any further. If more

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than one student appears red, she clicks on all those students' circles to see their current models and rules, so that she can prioritise helping the students who seem to be having the most difficulty.

From time to time, the teacher looks also at the GA tool. Knowing which students have accomplished all the task goals allows the teacher to offer them additional activities. Other students may be advancing more slowly; the teacher can use this information to set them additional homework so that they can catch up with their peers if they need more time than is available in the lesson. If the GA tool shows that many students are not achieving a particular task goal, the teacher can interrupt the lesson to help all the students at the same time by clarifying a goal that may be unclear or by providing additional guidance to help students' understanding.

At the end of the lesson, the teacher can use the ST to examine in detail what specific students have done. For example, if the teacher explained during the lesson to one student how to relate two patterns by using the same variable, she can check whether the student started doing this right away or required a period of 'trial and error' to understand the concept.

5. Formative Evaluation

During Phase C of the project, formative evaluation of the ST, CD and GA tools was undertaken with respect to the usage scenarios identified from Phase B. This formative evaluation comprised two parts.

The first part was a 3-hour evaluation session undertaken with 26 trainee Maths teachers on the Postgraduate Certificate in Education programme at the Institute of Education, University of London, who were split into two parallel groups of 13 for logistical reasons. Each of the participants had an installation of the MiGen system running on their computer. In the first half of the session, participants were introduced to the MiGen system as a whole and to the eXpresser tool. Participants were then asked to work through several construction examples using the eXpresser so as to gain familiarity with how students might use it in a lesson and the kinds of feedback the system would give to students. There was then a 15 minute break. In the following 30 minutes, each of the TA tools was introduced to the participants, using real data drawn from one of the classroom trials undertaken in Phase B. Using the time-stop functionality, the research team 'froze' the display of the data at a time 10 minutes into the lesson and explained to the participants the information that was being shown in each tool. For the final hour of

the session, participants were asked to move the display of the TA tools on their computer forwards, firstly to 30 minutes into the lesson, and then to 5 minutes prior to the end of the lesson. For each of these two time points, participants were asked to answer a short list of questions relating to usage scenarios US1–US6. At the end of the session, participants were asked to complete a similar questionnaire, this time relating to the full set of usage scenarios US1–US8. For each question, we also asked participants how they would tackle the corresponding usage scenario if the TA tools were not available to them. Two participants did not complete the questionnaires. We summarise below the answers of the remaining 24 participants with respect to each of the usage scenarios.

US 1. Finding out which students need the teacher's immediate help

For both time points (30 minutes into the lesson and 5 minutes before the end), 23 participants answered that they would use the CD tool and look for students whose circles were coloured red. Most responses for the first time point related to 'keeping an eye' on those students who did not seem to have had a good start and ensuring that those "marked with amber are staying focused". For the second time point, providing help to students seemed more important. Two teachers mentioned explicitly the functionality of clicking on the students' circles to see what the students have done, and if any are falling behind grouping them to help them collectively. Ten respondents gave detailed comments such as: "visual review of everyone's status helps you really check if students are understanding, without asking each of them individually", "allows much faster response to students' queries", "clearly highlights who is active and who isn't", "also shows what they have been doing which helps as sometimes, although the student is active, they may not be on task". Two responses went beyond using the CD tool and recognised that "GA also shows levels of progress" and can be used also for deciding which students need help.

With regards to finding out which students need immediate help without using the TA tools, 14 participants answered that they would use a traditional classroom solution, e.g. "walk around the classroom viewing students' work and helping any student who may be off task or needing help", or "'students would have to put their hand up for my immediate attention". Eight came up with more innovative solutions like using 'traffic light' cards to allow students to indicate if they are doing well (green card) or might be in trouble soon (orange card) or definitely need help now (red card), or even a remote control that would allow students to 'call the teacher'.

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US2. Finding out which students are progressing satisfactorily towards completing the task and which ones may be in difficulty.

For this usage scenario, for the first time point, 19 participants referred to the GA tool, e.g. "students who have yet to achieve any goals are in difficulty" or to a combination of GA tool with the CD and ST tools. Another five mentioned only the CD tool as a means of finding out in a glance which students are progressing. For the second time point, most referred to their previous answer or did not provide an answer. Two of the five who did answer said that they would use the CD tool, and one commented that it would be useful to have the ability to see this kind of information on a per task basis.

Without use of the TA tools, 23 participants stated again that they would use a traditional classroom approach, e.g. "periodically ask whole class re. stage of progress, level of understanding, plus constantly circulate to observe them at work and assist as required". Two of these responses contained a comment about the effort that this would require. One teacher came up with a more innovative approach: "I could get the pupils to personally fill in a tick box of how they have progressed, though this would take extra time and effort".

US3: Finding out which students are currently disengaged from the task.

For this usage scenario, all 24 participants provided an answer to one or both of the time points, demonstrating an appreciation to the fact that they would look for circles coloured Amber in the CD tool and providing answers such as "I would be most concerned about amber students who had yet to achieve any tasks". Again the difference between the two time points related to the level of the teacher's intervention. Some participants recognised that towards the end of the lesson students could be disengaged because they had finished with the task and therefore one approach could be to get "those who have finished to help those who are still struggling".

Some comments revolved around teachers' need to be able to configure the length of the time period that would cause a circle to be coloured Amber (this is an option that we subsequently added to the CD tool), and also ideas about the type of disengagement that may be occurring: it is different for a student to, for example, have the eXpresser open and be thinking about the task set or be discussing it with other students, and having the eXpresser minimised and playing a game or browsing the internet. One commented that students may be able to "game the system" as they could "figure out how to avoid amber by moving the mouse or dragging and dropping every n minutes". Some teachers therefore commented that they would have to

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observe the students' working as well, and some of them wondered whether it would be possible to see the students' screens on the teacher's computer. As there is existing software that can achieve this, we have not focused providing such functionality in our TA tools. Our view is that the disengagement information that is provided by the CD tool is a first sign for the teacher to do exactly what the participants mentioned, which is to approach the students coloured amber to find out who is actually disengaged from the task; or to use the information to choose which students' screens to observe using additional off-the-shelf software.

Without use of the TA tools, 22 participants answered that they would use again some traditional classroom solution. Three commented on the difficulty of doing this, e.g. "Difficult to keep an eye on all pupils, especially when you are helping one pupil in particular. Pupils often see you coming and switch back to task as you approach". Fifteen participants provided answers that demonstrated their appreciation of the TA tools in overcoming these difficulties, e.g. "The tools give you a clear indication of who is currently inactive or has stopped working on their task for over a minute. This gives you a clear indication of who might be switching off". Five provided elaborate comments demonstrating an appreciation also of the transformative nature of the information provided, e.g. "The tools provide a way of helping to increase the efficiency of my role as a teacher. By enabling me to look at the student tracking tools and the goal achievement tools I can readily identify those pupils that appear to be disengaged and subsequently target them for additional support/encouragement".

US4: Identifying common conceptual and procedural difficulties students are facing in order to provide more explanation to the class as a whole.

For this usage scenario, we asked the questions "Would this be a time-point that you would give more explanation to the class as a whole? And if so what would you say based on information from the tools?". From the 17 participants who answered, 9 referred to the GA tool and to the white cells that show lack of achievement of task goals; 4 would rely on the ST tool, but commented on its complexity for use during the lesson; 2 mentioned the CD tool but without providing any explanation; and 2 said that they would re-cap the task set for the whole class, and perhaps ask one of the students to demonstrate their solution, but did not explain why.

Once again, the difference between the two time points was the level of teachers' intervention: at the first time point, answers revolved around making sure that students were progressing whereas at the second time point

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participants were concerned with ensuring that students have achieved important objectives and with wrapping up the lesson.

Without the use of the TA tools, 15 participants provided comments, most involving walking around the class and either observing students or asking students of different abilities to explain what they had done. Two participants said that they would initiate a whole-class discussion, referring to critical observations they would have made while walking around the class. Two participants would employ some explicit (formative) assessment in order to ascertain the attainment level of the class but also commented on the difficulty of this approach.

US5: Finding out which students have finished the task

For this usage scenario we asked participants to give examples of students who had finished the task, as well as any additional comments they might have. 21 participants provided correct answers for both time points. 13 of these cited using the CD tool (the annotations of the number of goals achieved within the students' circles) and the rest cited use of the GA tool. Five participants commented on the ease with which they could check which students have finished the task. One participant said that close to the end of the lesson they would consider displaying GA information on the interactive whiteboard for all students to see and encourage the ones that that are behind to catch up. Three participants provided additional ideas on how they would take advantage of the GA tool: it could help them identify difficult tasks that they may need to modify, or allow them to choose which students to give extension tasks to.

Without use of the TA tools, all 24 respondents acknowledged that they would have to revert to a traditional approach whereby they would ask students who have finished the task to raise their hands.

US6: Finding out which students have achieved which task goals.

The results from this question were very similar to those for US5 above. Many participants replied "see above" or commented on the intuitive and simple usage of the GA tool.

US7: Providing appropriate support and guidance to individual students (i) during the lesson, and (ii) after the lesson. and *US8: Reflecting on the class' achievements and planning the next lesson.*

As these are more open-ended use cases, we asked participants to answer questions relating to them only in the end-of-session questionnaires. All 14 participants who provided answers showed an appreciation of the functionalities of the TA tools and how they can be combined to allow teachers to

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provide support to students during and after the lesson. Five stated that they would look back at the TA tools after the class to check which task goals were being accomplished and which were problematic. This would allow them to find out where and how students were struggling. Two commented that the CD tool could help in making sure that students who need immediate help during the lesson are supported, and that for those students who had not received enough help it would allow the teacher to plan to talk to them in the next lesson. One commented that having access to the TA tools "could be very helpful after the lesson to assess progress and decide which pupils need more support next lesson, and which pupils need stretching further". Two commented that seeing the indicators in the ST tool allows teachers "to identify the most common misconceptions which could then be consolidated in the following lesson", although both referred to the complexity of the ST tool for use during the lesson.

Two participants also commented positively on the eXpresser's feedback provided to students, which although designed to support students and not presented as part of the TA tool evaluation has of course the potential to assist teachers by reducing their workload in supporting the class.

Without use of the TA tools, nine participants provided comments that implied that they would adopt approaches requiring them to either walk around the class and check all students' work or to rely on students asking for assistance. They commented on the effort that this would require and the fact that it would be difficult to check students' work after the lesson class (the teacher would need to organise where students save their work so that the teacher could access it). Three participants said that they would rely on peer interaction and direct discussions between the students, and two referred to more innovative solutions such as "traffic lights" (similar to the answers for US 1).

The second part of the formative evaluation comprised a focus group meeting held with a group of pedagogical experts in maths education, to obtain detailed feedback to inform the development of the final versions of the tools in preparation for the summative evaluation in Phase D. The feedback resulting from this focus group meeting comprised (i) some change requests relating to the visualisations of all three tools, and (ii) the identification of a subset of 'important' indicators that are most relevant for use by the teacher during the lesson and that should be displayed by default in the ST tool.

6. Summative Evaluation

Phase D of the project included summative evaluation of the TA tools, comprised of two parts.

Part 1. The first part of the summative evaluation was a classroom-based trial involving one of our teacher collaborators at her school. This teacher had worked closely with us in Phase A and was one of the two teachers who had participated in a classroom trial in Phase B. A one-to-one discussion was first held with this teacher where she was introduced to the final versions of the TA tools and where she planned two one-hour lessons that she would undertake with a class of 28 14-year-olds using the MiGen system. During the first lesson, the TA tools were installed on a tablet PC which she carried around the class with her and consulted as she wished as her students were undertaking the task set in eXpresser. During the second lesson, which took place the next day, the teacher did not have access to the TA tools and had to support the students as they were working with eXpresser without having access to the information that the TA tools provide. The aim of this second lesson was to compare the difference in the teacher's experience compared to the first lesson in which she could access the TA tools.

During and at the end of both lessons, the teacher was asked a number of questions by a member of the research team, covering between them all the usage scenarios US1–US8, with the aim of evaluating the extent to which the TA tools meet the requirements of the usage scenarios. The questions are listed in Figure 5. A key objective when formulating and posing these questions was to disrupt the interaction between teacher and students as little as possible: we wished to introduce minimal additional cognitive load on the teacher, aiming for questions that could be answered quickly and yet precisely; also, we wished to impact as little as possible on the teacher's role in monitoring students' progress and in supporting students in completing the task set.

All the questions were designed to be answerable in less than 60 seconds. They were not asked if the teacher was helping a student, only when the teacher was moving around the class. The teacher was interrupted only three times during the lesson, each time for no more than 60 seconds, and was asked the questions at approximately the times shown in Figure 5. Additional questions were posed during a debriefing session after the end of each lesson.

In the first lesson — using the TA tools — the teacher was able to answer quickly and effectively Question 1 and Question 2. For example, when

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Question 1 (15 minutes into the lesson): which students are progressing satisfactorily in undertaking the task? [relates to Usage Scenario US2], which students may be in difficulty? [US2], which students need your immediate help? [US1]

Question 2 (at 25 minutes): which students may be disengaged from the task? [US3], which students have achieved Task Goal 3? [US6]

Question 3 (at 35 minutes): what common conceptual or procedural difficulties are students facing? [US4], what explanation might you give to the whole class at this time? [US4]

Question 4 (at the end of lesson): now that the lesson has finished, (i) which students have finished the task? [US5], (ii) what additional guidance might you give to any particular students? [US7].

Question 5 (after end of lesson): what are your views about the class' achievements in this lesson? how might you plan the next lesson? [US8]

Figure 5: Questions asked to the teacher during and after the lessons

asked "which students have achieved Task Goal 3?" she correctly selected the GA tool and pointed to the students who were being shown (in green) as achieving that goal. At the end of the lesson, the teacher answered correctly Question 4(i). During the debriefing, the teacher said that answering Questions 3 and 4(ii) required having a global view of the class' 'learning status' which was difficult to obtain from the tools (even more so, of course, without them). Regarding Question 5, she commented on her plans for the next lesson using the information provided by the tools to ground her arguments, e.g. "I see that there are several students that did not complete the last goal (general rule), so I will make a stronger point about it [next day] to make it clearer".

On the second day — without the TA tools — the teacher was able to answer the questions only in vague terms, e.g. "I think one of those students over there has finished". In the after-lesson debriefing, she commented that having access to the TA tools during the first lesson had made a real difference and that without them it was infeasible to obtain a "view" of the class, because paying attention to so many students required very frequent changes of context and "the forest gets lost behind the trees".

Part 2. The second part of the summative evaluation involved a 2-hour session held with a new cohort of 11 trainee Maths teachers on the Postgraduate

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Certificate in Education programme at the Institute of Education. Each of the participants had an installation of the MiGen system running on their computer. In the first half of the session, participants were introduced to the MiGen system as a whole, the eXpresser, and the TA tools. In particular, the TA tools were introduced to participants loaded with the real student interaction data as arising from the classroom trials undertaken in the first part of the summative evaluation and described above. Participants were asked to use the TA tools and the time-stop functionality to answer a short list of questions relating to usage scenarios US1-US6 at different time points in the lesson, simulating in this way the use of the tools in a real classroom. The questions are listed in Table 3. Participants were also asked how long they thought it would take them to answer these questions in a lesson (selected from 1 – Very little time, 2 – A little time, 3 – Average time, 4 – A long time, 5 – A lot of time), our aim being not only to determine if participants were able to use the TA tools to answer the questions correctly, but also how they perceived the amount of time that it would take them to answer the questions in a classroom situation.

All participants provided correct answers without any assistance from the research team. The graph shown in Figure 6 summarises the responses relating to the perceived length of time required to answer each question. We see that for all the questions no participant responded "A long time" or "A lot of time". The questions regarded as requiring the least time to answer were Questions 1, 4 and 5, most probably because they pertain to individual students and could be answered by consulting just one tool (the CD tool). Questions 2 and 3 may have appeared to participants as taking more time to answer because they refer to the classroom as a whole and because, in order to answer them, participants may have consulted the GA tool as well, and even the ST tool in Question 2 for a more detailed view of how students are progressing with their constructions.

Finally, at the end of the session, participants were asked to respond to the list of questions in Figure 7, relating to their perceived usefulness of the TA tools for the usage scenarios US1–US8. Question 1 relates to US1, Question 2 to US3, Question 3 to US6, Question 4 to US2 and US7(i), Question 5 to US7(ii), Question 6 to US8, and Question 7 to US4. Their response to each question was selected from: 1 – Totally Agree, 2 – Agree, 3 – Not sure, 4 – Disagree, 5 – Totally Disagree.

Figure 8 presents the responses relating to each question. We see that there are no responses of Totally Disagree to any question, and that only Q7

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- Q1. The session started 10 minutes ago (10 minutes into the lesson). If you chose a student to help immediately, which student(s) would you choose and why?

- Q2. Based on your experience and previous sessions you would have expected by now (10 minutes on) that students have achieved at least two goals. With a quick glance of the tools would you say that the class overall is going according to plan or would you intervene and why?

- Q3. We are at 30 minutes on. Based on your experience and previous sessions you expected that students would have finished by now so that you can progress on the next task. With a quick glance of the tools do you think that the class is at that stage and why?

- Q4. Sometimes students are off-task (e.g. play games). A 30 minutes on, find two students that are disengaged/distracted.

- Q5. We are at 30 minutes. Some students need help and you are trying to identify others who have finished and can help them. Can you give two examples of students who have finished?

Table 3: Questions asked to trainee Maths teachers for summative evaluation of the TA tools. Teachers were asked to answer each question and also record the time they needed to do so.

attracted 2 answers of Disagree. Q1, Q2, Q3, Q5, Q6 had mostly responses of Agree or Totally Agree. Q4 had 4 responses of Not Sure, and it related to using the tools to inform the provision of support and guidance to students during the lesson. Q7 had the worst pattern of responses, with 2 answers of Disagree and 4 answers of Not Sure, and it related to identifying common conceptual or procedural difficulties that students are facing. We discuss these results in more detail in the next Section.

7. Discussion

The results from both the Formative and the Summative evaluations of the TA tools are encouraging. The evaluation shows that teachers exposed
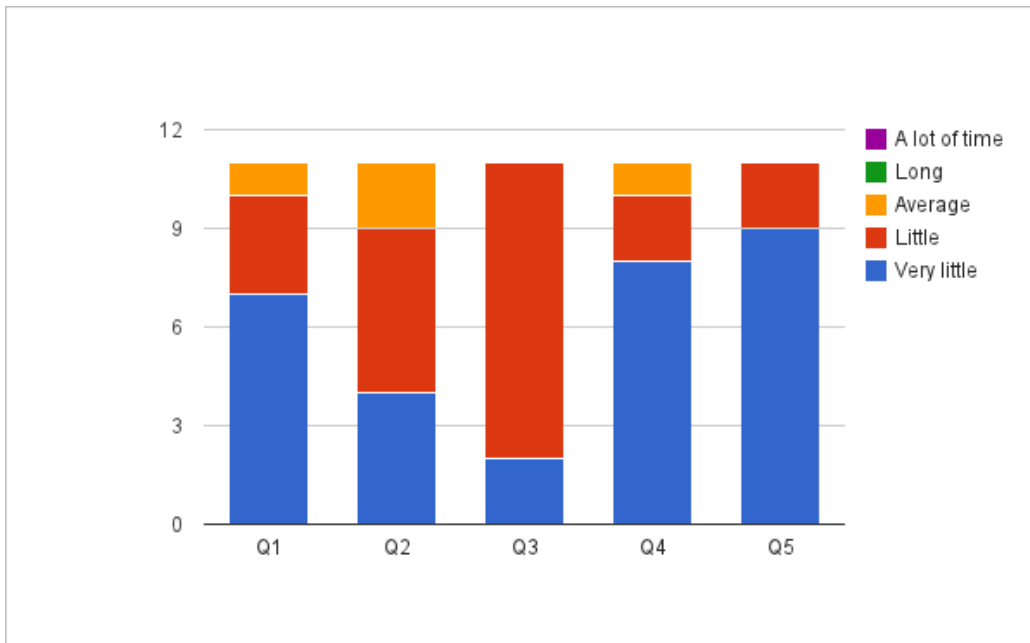
Figure 6: Participants' perceived time to answer the questions in Table 3

to the TA tools understand the capabilities of the tools and are able to use them effectively in answering most of the usage-scenario based questions.

From the analysis of the results of the classroom trial held with a teacher in her school as part of the Summative evaluation, we observed that the teacher was able to use the full suite of TA tools to address usage scenarios US1, US2, US3, US5, US6, US8 as she undertook a lesson using MiGen. As noted above, she had difficulty with US4 and US7. None-the-less, she reported being "extremely pleased" with the TA tools. One of the main reasons for this seemed to be the experience of control over the class that she was able to gain using them. With a quick glance at the information being displayed by the TA tools, this teacher was able to know which students were making good progress, which students were waiting for her help, and which students were falling behind with respect to the task goals. After the subsequent lesson, undertaken without using the TA tools, she reported that it was not possible to obtain a view of the class' progress for so many (28) students, and that having access to the TA tools during the first lesson had made a real difference.

From the analysis of the second part of the Summative evaluation, held

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I think that the Teacher Assistance Tools can help me...

1. ...in the classroom to find out which students need the teacher's immediate help.
2. ...in the classroom to find out which students are currently disengaged from the task or distracted.
3. ...to identify which goals have been achieved by which students.
4. ...to provide appropriate support and guidance to individual students during the lesson.
5. ...to provide appropriate support and guidance to individual students and reflect on the class' progress after the lesson.
6. ...to reflect on the class' achievements and to plan for the next lesson.
7. either in the classroom or after the class, to identify common conceptual and procedural difficulties students are facing in order to prove more explanation to the class as a whole in the current or the next session.

Figure 7: Additional questions asked to trainee Maths teachers for summative evaluation of the TA tools.
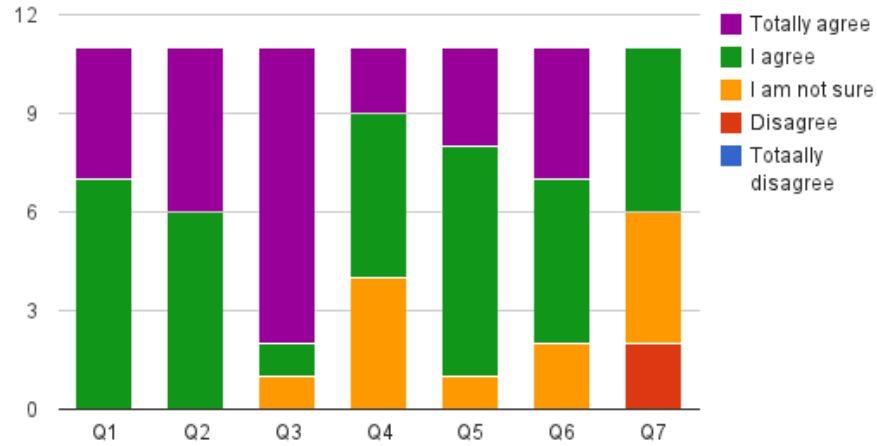
Figure 8: Responses to the questions in Table 7

with another cohort of trainee Maths teachers, we see that participants were able to use the tools to provide correct answers to questions relating to US1–US6 and that no answers were perceived as requiring "a long time" or "a lot of time". In the analysis of the answers to the end-of-session questionnaire, relating to participants' perceived usefulness of the TA tools, only Q7 (relating to usage scenario US4) had any answers of Disagree (2 such answers, out of 11 participants); Q7 also had 4 answers of Not Sure. Q4 (relating to US2 and US7(i)) also attracted 4 answers of Not Sure.

All of these results point to the usefulness of the TA tools for the identified usage scenarios. None-the-less, the limited number of classroom trials that it has been possible to undertake given the timescale and resources of the project, and the difficulties that some evaluation participants faced in using the tools for the more complex usage scenarios point to the need for further research, both in attempting to further elicit teachers' needs from such tools and in undertaking more classroom-based trials.

Although not directly related to the teachers' experience with using the TA tools, we would like to highlight that in the latest classroom trial (in Phase D) students reacted strongly when the teacher told them that she was

able to observe from her tablet PC what they were doing on their computers. It was apparent that the sensation of being monitored by the teacher led to better general behaviour and more focused work on the part of the students. We cannot tell without further empirical studies if this 'better behaviour under vigilance' effect would last if the TA tools were used on a regular basis, or whether students would soon return to their old habits. We believe that the effect could be a lasting one if students realised that their actions would have consequences, e.g. if they did not finish the task set in the lesson, the teacher would assign them finishing the task as additional homework, or would take non-completion into account in assessing their overall performance on this topic.

Finally, we believe that visualisation and notification tools such as Mi-Gen's TA tools that are developed specifically to support the teacher in an exploratory learning setting in the classroom are better able to provide a sense of awareness for the teacher than are general-purpose screen monitoring tools. Screen monitoring tools are not designed for continuous observation of the actions of many students during an entire lesson. Such tools would require a significant effort on the part of the teacher to follow and analyse students' actions comprising clicks, opening and closing of windows, etc. Moreover, such tools require large screens to be really useful, which is not feasible during a typical lesson, where the teacher generally needs to be able to walk round the classroom helping students in addition to using the tools to monitor the overall classroom state.

8. Conclusion

In this paper, we have described the iterative development and evaluation of a suite of Teacher Assistance (TA) tools that target an exploratory learning setting — specifically, the learning of algebraic generalisation. In order to design the tools and identify key usage scenarios we have collaborated with a number of teacher educators and maths teachers in secondary schools in the UK. Over the course of the MiGen project, we have conducted several one-to-one, small-scale, and whole-classroom trials in a number of schools, with 11 to 14-year-old learners and their teachers.

The results of the formative and summative evaluation sessions reported in this paper show that participants were able to use the TA tools quickly and effectively to address usage scenarios US1, US2, US3, US5, US6, US8 — concerning teachers' awareness of the classroom state, students' progress on

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achieving the task goals, students in need of immediate help, and reflection on the class' achievements — and that they appreciated the usefulness of the tools for these scenarios. There were some difficulties in using the tools for usage scenarios US4 and US7 — concerning identifying common problems students are facing and formulating their guidance to students. A small number of the participants noted that the information displayed by the ST tool would allow teachers "to identify the most common misconceptions which could then be consolidated in the following lesson", and this is a promising starting point for further research.

The development of time-stop functionality across all the TA tools allowed us to conduct evaluations of the tools with a far greater number of teachers (specifically, trainee Maths teachers) than those who were able to participate in classroom trials. The time-stop functionality allowed us to use real interaction data from classroom trials and present it to participants via the TA tools 'frozen' at particular moments in time, simulating in this way the experience of using the tools in a real classroom.

Based on the teachers' feedback from early classroom trials, we identified that installing the TA tools on a tablet PC helps the teacher to move around the classroom rather than having to return back to their desk to interact with the tools. It would be straightforward to adapt the tools to an even smaller screen such as that of a smartphone and this is an area of ongoing work.

Our future plans involve research into providing more targeted assistance to teachers for the more complex usage scenarios relating to identifying common difficulties that students are facing and formulating appropriate guidance for students. We are currently in the process of sharing the MiGen system with more teachers and disseminating our results to a wider community. We will continue to investigate how such assistance for the teacher influences the adoption of exploratory learning in the classroom.

Finally, it is important to note that the TA tools presented in this paper are general in their design and that such tools could be used to monitor the activities of students interacting with other exploratory learning environments provided that the environment detects appropriate interaction indicators. This would need to include as a minimum indicators relating to students' current activity status, waiting for help from the teacher, and goal achievement status: these are the indicators that drive the CD and GA tool visualisations which we have found that, in practice, teachers consult most often during a lesson. Our future work therefore involves investigating how

the TA tools could be adapted to support teachers using even more complex exploratory learning environments (such as that of the Metafora project (www.metafora-project.org) (Dragon et al., (in press), which focuses on meta-learning) and beyond that for virtual science labs, medical simulators, and interactive environments for novice programmers.

Acknowledgements

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