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Scaffolding Collaborative Learning Opportunities: Integrating Microworld Use and Argumentation

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Abstract. This paper presents our research efforts to support students' collaborative process when learning mathematics and science as they interact with microworlds and engage in discussions and structured arguments. The system provides students with an environment to explore challenging problems and encourages them to collaborate using a discussion tool to argue and share their rationales and insights using specific examples from microworlds. The challenge of providing useful analysis in such a situation is to recognize, across the learning environment as a whole (both microworld and discussion tool), situations where students need support, and then to make the learners aware of these situations in a productive manner. We present a use case that demonstrates how students work within the system and how we envision the system will provide support. We conclude that the analysis and support that we propose has the potential to enhance the benefits of a combined system and offer more support than a system focused on the individual tools separately.

Keywords: Collaboration, intelligent support, microworlds, argumentation, discussion

1 Introduction

Technological advances and research in technology-enhanced learning (TEL) have enabled at least two ways in which computer-based environments can support students learning mathematics and science. The first is through Exploratory Learning Environments (ELEs) including microworlds and simulations, which hold the promise of making abstract ideas more concrete and accessible [1, 2]. The second is through computer supported collaborative learning (CSCL) – and particularly dialogue and argumentation [3, 4, 5] – which provide students the means to engage in discussions and structured arguments.

The work presented here attempts to blend these two approaches to learning by integrating ELEs with a discussion and argumentation environment, thus enabling the possibility to learn in ways that were previously impossible. Some prior steps by members of our research team have been taken in this direction; for instance, the CoChemEx project explored the combined use of a virtual laboratory environment with a collaborative discussion environment, finding that scripted use of the integrated environment was easier and more supportive for students than a non-scripted environment [6]. The Rashi project also experimented with combining tools for data exploration and argument construction in a collaborative context, finding that the addition of collaboration increased the amount of student effort within the system [7]. Lastly, the WebLabs project, through the Webreports system [8], enabled distance collaboration of students who constructed models in the ToonTalk programming environment [9]. The project demonstrated the importance and positive effects of sharing, commenting, making changes and allowing students to reflect on each other's artifacts [10].

Integration of discussion and exploratory learning environments has the potential to provide unique learning opportunities. The visual integration of the tools allows students to support each other by easily sharing domain-specific information and knowledge. When one student has a better understanding of a situation than another, she can support her collaborator(s) by sharing information through examples within the integrated system, a form of peer tutoring. Even when there is no obvious gap in knowledge between learners, this approach can offer clear benefits over individual work by providing students the opportunity to discuss and argue about their work, promoting deeper understanding and bringing to light misconceptions. However, there is also potential for confusion or missed opportunity when students are working across multiple tools. Through our current work, we attempt to demonstrate methods by which the integration benefits can be amplified through intelligent analysis, intervention, and feedback.

This work is part of an EU-funded project (Metafora[1]), which aims to provide an holistic learning environment in which students will collaboratively plan and organize their work as they undertake complex activities over a relatively long time period. The environment is comprised of a variety of tools including several different microworlds for exploring science and mathematics concepts, a graphical discussion tool to support collaborative argumentation and reasoning, and a planning tool to support students' organization and time management. Each group of students uses a subset of these tools to tackle a given activity. This paper narrows the focus from the larger vision to a particular use case in mathematics. Students work independently in a mathematical microworld and simultaneously engage collaboratively in structured discussions about their microworld examples and the concepts that are represented by these examples. We introduce the types of information about learners that we intend to analyze and collect, and demonstrate how this information can be used to raise awareness and intervene directly with students when appropriate, increasing the chance that students will share their knowledge and help one another learn.

In the microworld, called eXpresser, students construct patterns of repeated building blocks of square tiles and their associated algebraic rules, as described in more detail in the next section. Underlying this goal, the main objective is to promote students' appreciation of the expressive power of algebra [11, 12].[2] In parallel, students engage in discussions within LASAD[3], a web-based argumentation tool that

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[1] http://www.metafora-project.org
[2] eXpresser was developed in the context of the MiGen project (see http://www.migen.org)
[3] http://cscwlab.in.tu-clausthal.de/lasad/

allows groups of learners to discuss their work in a structured way [13, 14]. LASAD is a collaborative, shared workspace containing a graphical argumentation environment and a chat tool. Students use this space to share ideas and organize their thoughts as they learn new concepts, and discuss or argue. The Metafora system brings these tools together, providing a framework and communication system that allow students to easily move between the tools. Students opportunistically work on their eXpresser models, share them, and discuss them within LASAD, as exemplified in the next section.

Both eXpresser and LASAD have pre-existing analysis components that can provide intelligent support. Several computational components analyze students' interaction in eXpresser and a rule-based system offers suggestions or hints designed to help them complete the task they are undertaking [15]. The LASAD tool offers a generic framework for feedback [14] and a rule-based system that offers advice on the structure of arguments, such as whether "claims" are supported by "facts" or whether "questions" receive "responses." Metafora then provides the means for the individual tools to contribute their analyses to a shared analysis channel, where the information can be combined.

Our proposal is that the combined output from these analyses can be further analyzed to offer a better model of the students' current and potential collaboration than either system could provide individually. To demonstrate the functionality of the system and the potential for improved modeling of student activity through integration of tools and analysis, section 2 presents a specific use case to illustrate how students work within the unified system and how it might respond. Section 3 discusses our generic cross-tool analysis approach and section 4 summarizes the overall approach and presents the direction of future work in this regard.

2 The Integrated Microworld and Discussion Environment in Use

2.1 Context

This scenario is meant to highlight the potential benefits and challenges of integrating microworld and argumentation tools in a pedagogically meaningful way. We seek to demonstrate how analytic information collected about the students from individual tools can be combined to recognize situations where students might be able to help one another, or where the students might benefit from outside intervention. We contend that the support described in these two situations demonstrates the potential for combined analysis to increase the chances of learning benefits for the students as they work with the different tools.

The activity given to students in this scenario is to use the eXpresser microworld to derive algebraic rules that correspond to structures of their own design, and are general across variable values. Specifically, in eXpresser, students construct their own 'models' made of patterns of repeated square tiles. These models contain variables with changing values, enabling the construction of a dynamic figure that animates. For example, Fig. 1 shows a student's construction of a model that is comprised of two patterns, denoted in red and green to the student. The red pattern (made of a building block of 2 tiles) is repeated horizontally 5 times. In an effort to specify what is constant and variant in the model, the student specifies that the green pattern (made of a building block of 5 tiles) is repeated 'one more time' than the red building block. To create this description, the student creates a variable called 'gaps' to represent (what she perceives as) the number of gaps in the model (i.e. the red pattern). In order to color the model, the student has to specify algebraic expressions that represent the number of tiles in each pattern and subsequently define the model rule that represents the total number of tiles in the model. It is evident that the same model can be constructed in a variety of ways, leading to different model rules (e.g. 7*gaps + 5). In the scenario we describe here, the description of the task encourages students to construct structurally different models.

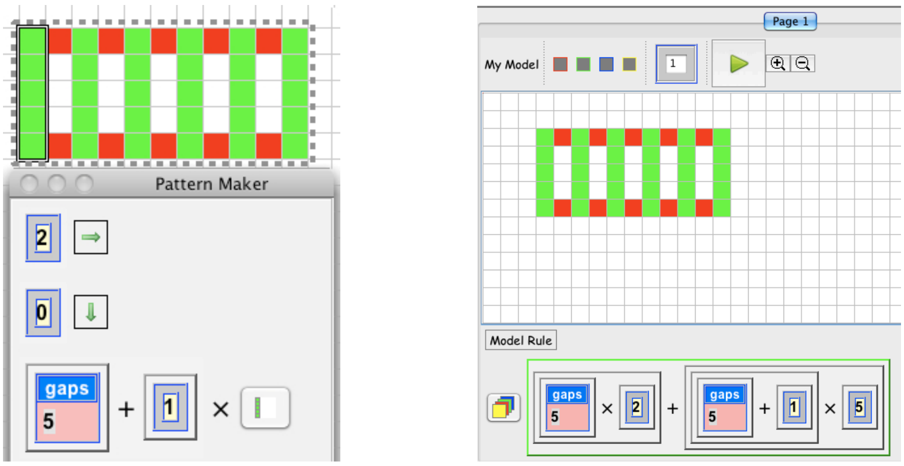

Fig. 1. A student's construction in eXpresser. On the left the properties of one pattern (the green) as it is constructed. The red pattern has been specified similarly with the red building block repeated 5 times, which is the current value of the 'gaps' variable. This can change when the model is animated, so for the green pattern, one should specify that it should be repeated always 'gaps' + 1 times. On the right a general rule of the total number of tiles in the model.

Subsequently, a collaborative task encourages students to discuss the correctness and equivalence (or non-equivalence) of their derived rules. This task challenges students to read, deconstruct and match their rule with their own model as well as with their partner's model. In previous work we have established the benefit of these collaborative tasks; they provide students with opportunities to reflect on their interaction with the system and develop strategies to justify the correctness and equivalence of their rules [16]. We now envision that students are given this task within the Metafora system, which provides access both to eXpresser and LASAD. The students can use LASAD to share and discuss their models and rules with the other students in their group. Ultimately, the goal is that students to reach an agreement and understanding of the importance, possible differences, and usage of algebraic rules.

2.2 Scaffolding opportunities during model construction

In the first phase of this activity, students work individually within eXpresser, but have the ability to use LASAD to discuss their work. As the students interact with eXpresser, the software gathers information about the students' work, looking for significant events that demonstrate important information about the student, which we call *landmarks*. Landmarks are a concept general to the Metafora analysis framework, representing high-level, interesting information about a student or group of students that might be shared across tools. Examples of landmarks include achievement of certain goals in eXpresser, rating of someone's activity in LASAD (e.g. labeling certain users as 'helpers' because these user tend to answer other's questions), or recognizing other traits of users such as "random manipulation" vs. "systematic experimentation" in other ELEs. These landmarks are collected and considered in order to provide the cross-tool support, as described in more detail below.

We now consider a situation where one student, Alice, is working in eXpresser and achieves the landmark of creating what is referred to as "general model," i.e. a model that is structurally impervious to changes to the value of its variables. The analytic tools of eXpresser recognize and report this event to the analysis channel in the Metafora framework. The Metafora analysis component maintains a list of these landmarks and the students that have achieved them, as this information is useful to both the teacher and to the system. Shortly after this time, the system recognizes that another student, Bob, is struggling with the construction of a general model; Bob has made repeated failed attempts at the same landmark. The LASAD tool reports any interaction between students over the analysis channel, so the system also recognizes that Bob is not discussing the situation with anyone.

Given all of this information, the system decides to intervene. It recognizes that Bob is struggling by himself, and that Alice is a potential helper, because she is known to have built her own general model (this decision can also be influenced by a landmark about Alice being a 'helper' in LASAD). If the system took no action, Bob might continue to struggle in reaching his own generalization, or the two students may discuss the situation on their own. However, rather than waiting and allowing Bob's potentially misguided efforts to continue, the system chooses to offer support, which can come in one of two forms. First, the system can send messages to both students asking them to discuss the situation. A message is sent to Bob that asks if he would like to discuss an issue with someone from the group. Subsequently, a message is sent to Alice asking her to discuss with Bob. Second, the information about Bob's struggles could be conveyed to the teacher who, in turn, could interact with Bob or encourage Alice to discuss with Bob.

In either case, the students are supported to carry out a conversation that helps Bob understand the concept of a general rule through an example (see Fig. 2). This action is supported within the system through the use of special boxes within LASAD that help students express the issues they are facing within the microworlds. These boxes include a snapshot of the student's work, as well as a "Go to Microworld" button that allows anyone to view and manipulate the shared model. In the given example, Bob creates one of these "Microworld Issue" boxes in LASAD to describe his problem (Fig. 2 Box 1). Alice tries to help him by offering suggestions and answering questions, eventually providing an example from her own eXpresser work (Fig. 2 Box 20) to help clarify.

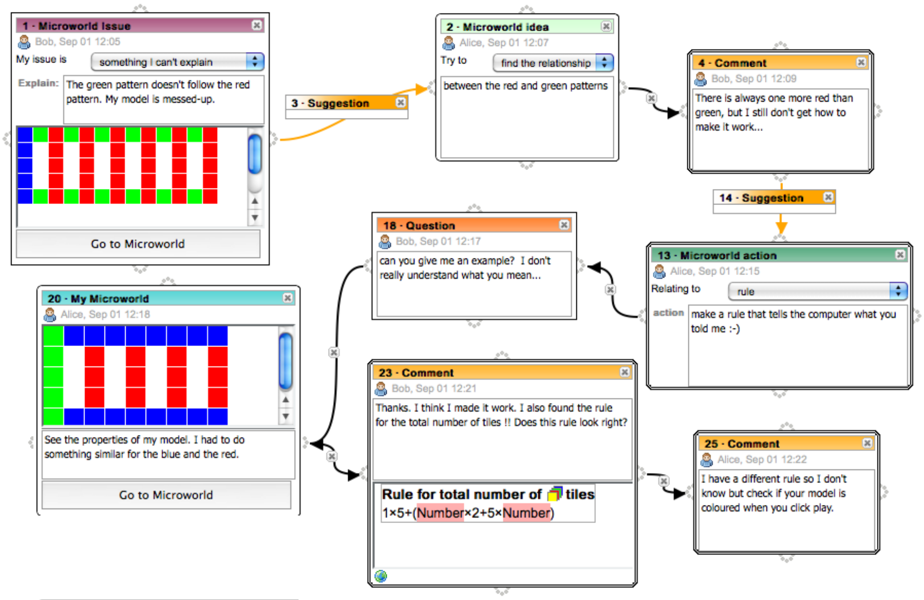

Fig. 2. The discussion that occurs between Bob and Alice, where Alice shares her model and understanding of general rules with Bob.

As their interaction unfolds, we can see the potential for further analysis from the LASAD system. The system can recognize nodes that would generally require some type of response, for example a "Microworld Issue" node (Fig. 2 Box 1) or a "Question" node (Fig. 2 Box 18). In the situation given above, the system recognizes that Alice is responding to these nodes by making her own nodes and connecting them to the issue and question nodes. Since there is active participation, no further intervention is necessary. Had there been a lack of response, the system could again prompt students or alert the teacher.

This example demonstrates how combined tools that allow students to easily share examples create an opportunity for collaboration and peer tutoring that would be more difficult, if not impossible, with stand-alone versions of the tools. At the same time, the situation demonstrates how intelligent support can help to assure that these opportunities for fruitful collaboration are not overlooked. In this example, the system can recognize when specific students are unaware of their unique potential to help to one another, and encourage these students to share.

Similar tactics for encouraging students to help one another have been suggested in prior work on the Rashi project where the system used an expert knowledge base to recognize differences between student knowledge and then elicit conversation about these differences [17]. This idea is also grounded in research where tutor-tutee roles are more clearly defined, and the potential for peer tutoring is made clear [18]. Further, this approach is supported by past classroom trials where microworlds were used in classrooms and teachers paired students to help one another (e.g. [16]). The approach was further supported by pilot trials with early prototypes of the Metafora system. So we see that the need and success of this general type of intervention are recognized from both experience and theory.

2.3 Scaffolding opportunities for reflection and argumentation

In the next stage of activity, students pair up with another member of their group to discuss the correctness and equivalence of their respective models. To simplify our discussion, we assume here that the teacher motivates the shift as students complete their work with the models, but the shift could also be encouraged by the system, which has collected the information on which students have successfully found a general rule for their model. In our example, we imagine that our student, Bob, is brought together with a different student, Maria, and asked by the teacher to discuss the equivalence of their two models. Fig. 3 shows an example of the discussion that follows in LASAD. As in the previous stage, we see that the integrated system provides unique opportunities to share their learning objects and understanding. Once again, the students are able to create specialized boxes that demonstrate their work in the microworld, and provide a way for students to explain this work (e.g., Fig. 3, Box 6 and Box 15). Comparing their work would be significantly more difficult if the models and rules needed to be described using words rather than images. In Fig. 3, we see how the two students' work can be seen side by side.

Similarly, we can also see the possibility for intelligent support to recognize situations that could require some type of intervention. In our example below, we see that both students consider their rules to not be equivalent, and for different reasons (Fig. 3 Box 21 and Fig. 3 Box 25). The LASAD system can recognize the values set in these equivalence nodes, allowing the analysis system to understand whether students agree or not. However, when adding the knowledge from the eXpresser analysis that these rules actually are equivalent, we recognize a situation where both students in a group seem to be mistaken and therefore some intervention might be required. In this case, we demonstrate the role of the continued need for the teacher to provide support, as she may be able to help students through this perceived impasse. The teacher is made aware of the issue (she is alerted to the fact that both students have incorrectly identified equivalence), and she responds by giving them feedback about their "Rule Equivalence" nodes (Fig. 3 Box 30). She provides a suggestion to help them reflect on their rules and on the discussion. This leads Maria to realize the need for a more descriptive name for her variable. Even this simple prompt from the teacher is enough to scaffold the students' collaboration process, which continues with both learners revising their rules (e.g. Fig. 3 Box 33). Continuing to monitor the discussion, the teacher uses this opportunity to ask the students to reconsider their answer (Fig. 3 Box 39). She does this by pointing out Bob's previous contribution (Fig. 3 Box 25), which was earlier ignored.

Here again we see the benefit of combining analysis across tools to create a more precise model of the students' state. We also see the benefit of involving the teacher through alerts rather than directly intervening, as the teacher can offer feedback that is more specifically catered to the student's comments than an automated system could provide.

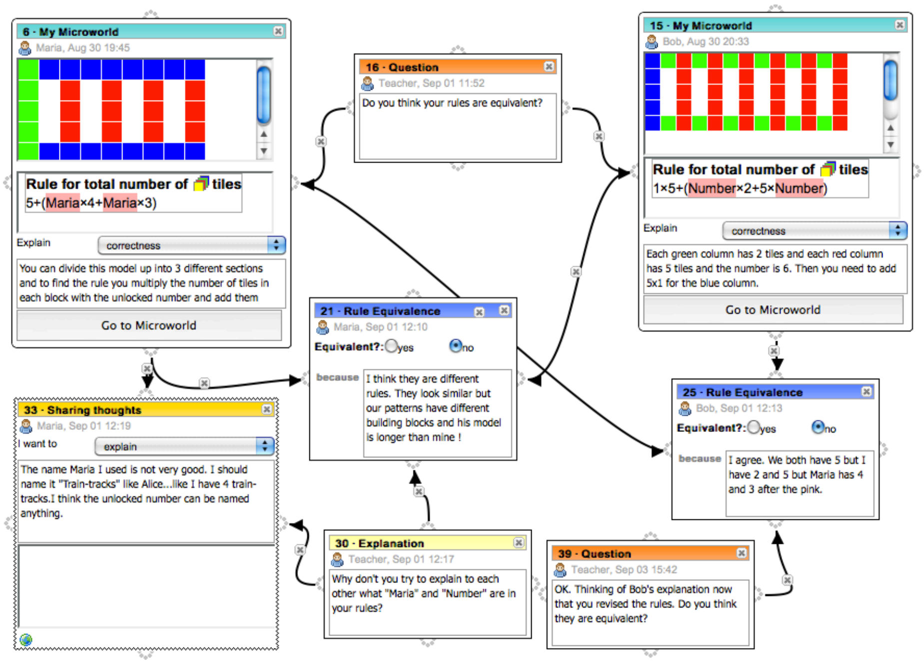

Fig. 3. An example of a LASAD discussion where students discuss the equivalence of their eXpresser models.

3 Generic Cross-Tool Analysis

We have described a scenario in which an integrated microworld-discussion system could provide benefit to collaborating students, and described how combined analysis across tools can increase these benefits. We now discuss our approach to creating a system that can handle the above-mentioned situation in a generic, standardized manner when considering students working in the context of different activities, and with different tools. In this way, we describe how the analysis agent for the overall Metafora system can recognize and take action to create the scenario described above.

The over-arching Metafora system maintains multiple communication channels for the interaction between tools: an analysis channel where tools' analysis components can report findings; and a command channel, where the system can instruct tools to display specific states or offer feedback to a specific end-user. The server records the incoming data from the analysis channel to a database. Cross-tool analysis agents take information directly from the analysis channel or from the database to provide alerts to teachers and/ or interventions to the students through the command channel.

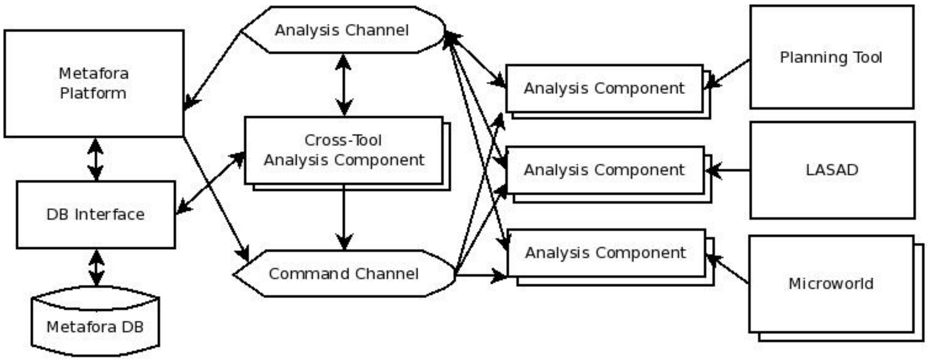

Fig. 4. The communication structure between tools in the Metafora system.

To utilize these communication channels, there must be some common "language" or set of abstractions that the tools share in order to create log information that can be analyzed in a generic fashion. Providing a method of abstracting student actions in order to allow for unified analysis of the integrated learning system allows the generic Metafora analysis system to benefit from the analysis completed by individual tools while not having to understand the specific interworking or domain knowledge of any particular tool. The basic definition of this abstraction in the Metafora system breaks down into three levels, from most to least fine-grained:

- *Indicator*: a statement of user activity from any tool in Metafora; indicators require minimal analysis to recognize and report, yet are interesting to help analyze student work.
- *Tool-specific landmark*: a high-level statement about competence (either accomplishment, or need for remediation) of a user or group within a particular tool, requiring serious analysis.
- *Cross-Tool Landmark*: the concept of a landmark taken beyond a single tool, to encompass other indicators and other landmarks across multiple tools and potentially multiple students.

Each tool reports this processed information about the current learners to the Metafora system (indicators and landmarks), and receives feedback information from the system to be presented to a user or a group of users. The challenge for the analysis agent on the Metafora server is to decide which indicators and landmarks for the given task and tools are important and worthy of action and/or feedback. In our first example, where Alice helped Bob, we see that one relevant piece of information from the microworld was a landmark, in this case the accomplishment of the high-level task "creating a general model." Recognizing that Bob was struggling to achieve this landmark, the system searched the database for a discussion partner that was known to have achieved the landmark.

The second situation, where Bob and Maria discuss equivalence, is more complex. The Metafora analysis system is aware the student discussion potentially contains boxes that represent "Rule equivalence". These boxes are linked with that specific landmark from eXpresser. The discussion tool provides a landmark when it recognizes consensus between students (i.e. that both students marked “yes” to the equivalence and connected the same models). The analysis system must then consult the analysis component of eXpresser to decide whether this consensus between students is mistaken. When it recognizes that both students are mistaken, it can report this situation to the teacher in the form of a cross-tool landmark “mistaken consensus.”

Following these examples, one can see how the abstraction layer allows the Metafora system to focus on these landmarks, a measure of achievement (or lack thereof) rather than on domain-, task-, or tool-specific information. In this way, any tool that can produce these types of landmarks could be supported in the same fashion by the Metafora system. We see the example of the system identifying struggling students and pairing them with other students who have success on the landmark. We also see the system recognizing consensus about a landmark within a tool, and providing the teacher with information if that consensus seems faulty. Obviously, there are many such approaches and each will have to be vetted in the classroom to understand the impact of such intervention. That said, one can clearly see the power of the given approach to offer generic analysis across tools, increasing the likelihood of productive collaboration.

4 Conclusions

We have presented a system that combines microworld experimentation with a discussion tool. This system offers benefits over stand-alone tools by providing the ability to share work within conversation and use specific visual examples. We propose that the combined analysis from these tools can provide support to specific learners at specific times in order to make their efforts within the system more productive. We have shown examples of when such analysis might be useful, and how it can support student efforts. Finally, we presented a communication structure, abstraction layer, and method by which this type of support can be given in a generic manner across different tools.

With this effort, we also suggest a path that fellow researchers might follow in attempting to introduce collaborative activities into their current systems, or combine current systems to create collaborative workspaces. We also demonstrate how current intelligent feedback agents can be integrated and extended to work with information across multiple tools by using simple message passing with a common method of abstraction. Such an approach can offer a solid foundation for taking many currently independent and specialized tools and creating a collaborative workspace that can offer holistic, intelligent support to students. Furthermore, we have illustrated that such an approach can actually provide means of additional analysis that can inform teachers and support students beyond what the individual tools can offer.

There is still much work to be done to fully implement and evaluate this system and technique. Future work includes a teacher interface that will allow teachers to access and respond to the given information, building on previous efforts in the Argunaut and MiGen projects [19, 20]. Another major challenge will be to recognize, catalogue, and respond to a wider variety of situations where support can be offered, beyond the two described above. Related to this, we need to identify a set of generic indicators and landmarks that apply over a wide variety of situations. We will employ several tactics, including taking advantage of more information than individual tools can offer, such as information from the user-modeling components of these tools, which store present or historic information about the user. MiGen, for example, stores several indicators and landmarks and infers goal accomplishments and other information about the students (see [20, 21]). Another method of adding power to our analysis approach will be to strengthen the individual tools' ability to offer landmarks about student work. For example, as the analysis system for LASAD matures for this specific application, it could offer landmarks addressing more complex situations including at least some analysis of text contained within the boxes created by students as accomplished in the ARGUNAUT project, where graph and text matching techniques were used to identify certain critical exchanges between students [19]. Finally, there is the issue moving beyond analysis and considering possible intervention techniques. Here we consider prior work on the Basilica project, where conversational agents offer support to students interacting in varied learning environments [22]. With these improvements to the modeling from the specific tools and definition of the precise method by which the Metafora analysis agent can interact with students, the potential benefit of this integrated system and cross-tool analysis grows ever more promising.

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