Learning technology-enabled (meta)-cognitive scaffolding to support learning aspects of written argumentation

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Abstract

This paper[1] reports on an AI-informed and NLP-based work in progress. It shares the technology, educational and cognitive approaches for enabling science students to engage with automated (AI) personalized (meta)-cognitive scaffolding to learn aspects of written scientific argumentation. We briefly report on the features and functionalities of MindWare technology and preliminary and brief results of a small-scale pilot to gauge the impact of technology-mediated scaffolding on students' learning of how to argue (in written form).

CCS Concepts •**Computing methodologies** → Cognitive computing

Keywords Cognitive Computing, Learning Technologies, Argumentation, Natural Language Processing, Science Education.

1 Introduction

Research in the area of metacognition and scaffolding for learning emphasizes the need to provide adequate, sufficient and timely external support to enable the enacting of the students' metacognitive processes [1]; [14]; [29]. The past few years have seen a surge in research related to technology-mediated assessment of written output by foreign language learners and learning analytics-informed reflective writing [36]; [15]; [16]; [10]; [3]; [34]. The use scaffolded automated feedback to support metacognitive learning of written argumentation is, however; an underexplored domain. This work is a contribution to this domain, with a specific focus on application in the context of science undergraduate education.

Most commonly, scientists learn to develop a written scientific argument by mimicking their supervisor, peers and scholarly papers in their discipline. It is increasingly recognized that for students to effectively develop argumentation skills, they must explicitly learn how to argue and reason [22]; [18]. This is because to develop or critique an argument, students need to explicitly learn how to advance claims, take stances, justify ideas they hold, and be challenged about the ways they construct their arguments [19]; [46]. Hence, to develop their argumentation skills, students need to gain an understanding of the meta-linguistic and meta-cognitive features of argumentation. Explicit teaching of written argumentation in science might, however, seem an overwhelming challenge as it requires both content knowledge and knowledge about how to structure a written argument.

Cognisant of these challenges, we developed a learning technology, dubbed MindWare, to provide iterative formative feedback on written argumentation as a support for instructors and students at our university. In this paper, we: (a) provide a brief overview of the pedagogical, computational and cognitive approaches that the learning technology is based on and (b) briefly report on the preliminary results of a small-scale pilot of the tool.

2 Personalized Learning Environments and Scaffolding

Personalized learning is a pedagogical approach that puts the learner, their progress, and their learning at the heart of the pedagogical experience [8]. This approach allows students to proceed at their own learning pace, and can be supported by a combination of human and automated processes. The use of automated processes requires technologies that give students control, actionable information, and feedback, and allows them to take responsibility for their own learning. When used in a course, learning technologies that support personalized learning are expected to monitor individual students' progress at a micro-level, and supply automatic feedback [8].

The pedagogy of learning to argue and arguing to learn [36]; [10], suggests that personalized learning environments need to cater to both the cognitive and the meta-cognitive aspects of learning to argue. There is reason to believe that such an approach lends itself to pedagogically sound scaffolding [48]. We define scaffolding as providing need-based assistance to students. Effective scaffolding requires that the *why*, the *what* and the *how* of the scaffolding is related to the expected assessment methods and learning outcomes [2]. In our case, this included explicit scaffolding of the usages of the argumentation voices of hedging, stancing, and logical connectors in written argumentation, as produced by several drafts of essays written by students as parts of their formative assessment in a First-Year Seminar (SCIE 113) course where students learn to construct and deconstruct (scientific) arguments [5].

3 The metacognition of argumentation

There are at least three approaches to argumentation: (a) argumentation as a logical product (b) argumentation as a rhetorical process and (c) argumentation as an epistemic tool [6]. We adopt the perspectives in (b) and (c). We assume that written language is the direct cognitive by-product that externalizes how students build arguments supported by evidence. We define argumentation as a complex meta-cognitive act produced by a writer, and evaluated by a reader. Assuming that language is core to learning and that thought and language are inseparable [38], examining students' argumentation offers opportunities for gaining insights into how students engage in scientific reasoning.

Drawing on the reasoning above, we assume that the argumentation voice exhibited in student essays is a direct window to students' reasoning. This reasoning is externalized, in written form, through the way students formulate a claim (premise/thesis statement), how they elaborate on that premise, how they hedge, take a stance, and the logical connections they adopt in their essays. We further assume that in the process of taking the argument from an initial draft to writing the final product that will be submitted for summative assessment, the students would have engaged in many meta-cognitive aspects related to written argumentation.

To enable the students to engage in the cognitive and the meta-cognitive aspects of learning to argue (in written form), there are a set of pedagogical requirements that need to be met by the scaffolding process-es, enabled through learning technology. These requirements which we derive from the literature of metacognition for learning [12]; [47]; [49]; [7] include following: (i) learning technology functionalities that help students monitor their own thinking process, (ii) internalize self-monitoring techniques, and (iii) develop higher order cognitive processing techniques (through asking higher order questions) [12]; [47].

4 Technology-enabled Scaffolding of Written Argumentation Voice

The past decades have witnessed an increase in studies that investigate students' argumentation skills in educational contexts and how these might be enhanced [38]; [27]; [41]; [28]; [42]. As Scheuer *et al*. [33] observes, (automated) support for learning argumentation is missing from most formal courses. To address this gap, many technology and learning scientists embarked on the exploration of different technology designs to support aspects of representing argumentation to simulate and diagnose reasoning [42]; [40]; [44]; [10]; [43], and to support conversational argumentation [35]; [39]. This has led to the development of a number of technologies that are designed to improve learning through diagramming argumentation [19]; [43], and to enable scaffolding and argumentative communication through visualization [44]. In parallel, with this work on how to (re)present an argument, the last two decades have also witnessed the emergence of advanced techniques for mining different aspects of argumentation from text. This includes the automatic classification of argument components [34]; [10]; [35], the identification of argumentation structures [45], and the separation of argumentative from non-argumentative text units [14]; [42].

We build on these general approaches to mining and representing aspects of argumentation, and on the specific insights that relate to how computational argumentation methods can be used to analyze essays for pedagogical purposes. In this respect, the general computational argumentation method that we have adopted relates to that of Persing and Ng [27], Song *et al*. [34], Walton *et al*., [42] and Klebanov *et al* [28]. We share with these scholars the goals of extracting argument structures from essays by recognizing (structural) argument components and jointly modeling their types and relations between them.

MindWare (our software), a beta version at this point, has two clusters of functionalities one for the students and one for the instructors. The instructors in our educational context are scientists and do not have any training in language sciences and argumentation analysis *per se*. The usage of MindWare is intended to complement the feedback provided by the instructors, such that they can focus their feedback on content, such as the quality of the evidence provided in support of the argument. The software is designed to provide feedback on students' written argumentation voice, focusing specifically on the usages of hedging, stancing, logical connectors and coherence. Students submit a number of drafts (the number to be set by the instructor) and the performance of the students is visualized in a set of color coded gauges, heat-maps and graphs that provide students with feedback on the aspects of their argumentation that require improvements (see Figure 1).

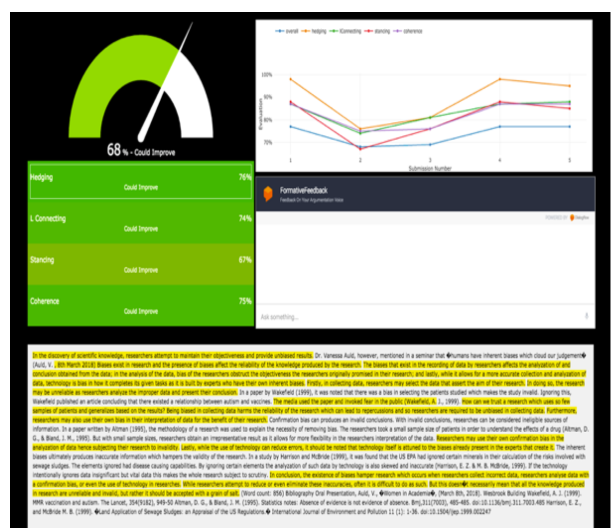

Figure 1: Dashboard of feedback for students

The dashboard also provides feedback on students' performance on aspects of their argumentation across different drafts of their essays is also displayed. (see Figure 1). Instructors can use the software to view the submissions and the performance of a particular student, and/or a of group of students, and they can see which aspects that students commonly struggle with in terms of mastering the components of the argumentation voice, and as such can design pedagogical intervention accordingly. Instructors are able to do this through having access to a dashboard that provides the instructors with an overview of different aspects of argumentation in students' essays. For example, in Figure 2, the heat map provides an overview of the areas of argumentation that the class is struggling with. The heat map with areas colored in yellow and red indicates aspects of written argumentation that some of the students in that course section are struggling with, and which requires the pedagogical attention of the instructor.

Figure 2: (Partial view of a) dashboard for the instructor

In terms of the computational model, MindWare is equipped with Natural Language Processing and Machine Learning modules that analyze and weigh the usage of the components of an argumentation voice, viz., the balanced use of stancing, hedging, logical connections, and coherence. For example, MindWare can identify and evaluate the degree of stancing in an essay [10]. That is, whether the writer is arguing for a specific stance. In contrast to describing, stancing is used to express one's position. When writers take a stance, they not only express factual information but they also indicate their commitment with regard to what they said/wrote. The presence (or the lack thereof) of the components of the argumentation voices of stancing, hedging and logical connections can shape the reader's opinion of the writer and of their argument in such a way that succeeds (or fails) to convey an adequate epistemic vigilance on the part of the writer.

5 Gauging the Impact

In this study, we piloted MindWare with the aim of supporting the metacognitive processes that underlie learning aspects of written argumentation in the context of a first-year science course. Part of our scaffolding strategies were planned in advance and focused on enabling and supporting the learning of the aspects of written argumentation, aspects that are crucial for establishing an argumentation voice in an essay as they are inherent in the exercise of epistemic vigilance within a written text [6]. This includes the (balanced) use of hedging, stancing, logical connections and coherence as indispensable components of an argumentation voice.

The AI-based machines in MindWare weigh the usage of these features in an essay and provide feedback (in visual and numerical form) to the learner. Other parts of the scaffolding in MindWare are provided dynamically, based on the response of the student, and such scaffolding is supported by an automatic feedback. An overview of the metacognitive scaffolding strategies we employed in MindWare is provided in table 1.

Table 1: Metacognitive scaffolding strategies in MindWare

Metacognitive scaffolding	MindWare Interface
Monitoring the use of hedging, stancing and logical connections	Learning analytics dashboards, including information about: differences across drafts of an essay, feedback on specific aspects of the argumentation voice, highlighting of relevant text passages within the drafts of the essays.
Evaluating the use of hedging, stancing and logical connections	
Revising the use of hedging, stancing and logical connections	

To gauge the impact of MindWare, in particular its ability to enable metacognitive scaffolding and support the use of argumentation voice, we conducted a small-scale pilot in a first-year science course. Our pilot was run in two course sections of the same course. Each section had 25 volunteering students, and with students having the option to pull out of the study at any time when/if they want. Data collection was carried out in three stages and data of students who did not complete all the three stages was discarded.

In stage one, students responded to a pre-task survey, gauging their familiarity with the investigated concepts (hedging, stancing and logical connections), and the confidence level in using such components. Only after completing stage one, students were granted access to MindWare. In this stage, they were invited by the course instructors to submit a maximum of five drafts of their written essays, and explore the software, including receiving feedback before submitting the final version to the instructor for final assessment and grading. In this process, students were granted access to interact with an artificial agent to ask questions about different aspects of written argumentation and get automated feedback. In this stage of the pilot, 26 out of 50 students worked consistently in MindWare environment. This stage lasted for two weeks. After submitting the final version of their essay to the instructors, in stage three, students were asked to respond to a set of survey questions to reflect on their learner experience and specifically their perceptions about their own performance regarding the usage of the components of the argumentation voices in their written scientific essays. Of the entire cohort of 56 students, 54 participated in stage 1, 26 participated in stage 2 and 19 responded to the post-task survey.

On a scale of 1 to 10, students were asked to rate their familiarity with the indispensable components of the argumentation voices of hedging, stancing and logical connections in an essay. The left part in Figure 3 provides an overview of the pre-task survey responses. In the pre-task survey responses, only 15% of the students indicated that they are familiar to very familiar with the components of the argumentation voice of hedging, stancing and logical connection. After two weeks scaffolding through the use of MindWare, 51% of the students reported that they were very familiar with how to use the components of the argumentation voice in written essay.

Before scaffolding in MindWare

After scaffolding in MindWare

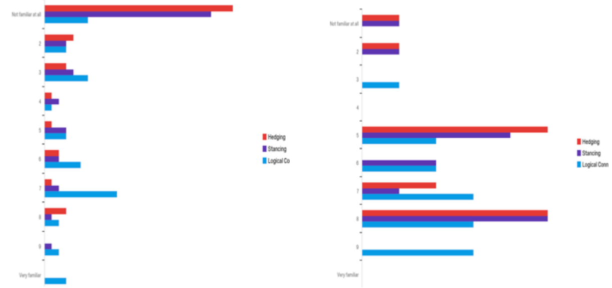

Figure 3: Familiarity of the students with the components of the argumentation voice (pre-task and post-task responses).

Likewise, we observed that the confidence of the students in using the components of the argumentation voices in their essays increased. In the pre-task survey, 17.33% of the students reported that they were confident to very confident in using the components of the argumentation voice in their essays. Compared to the pre-task survey, in the post-task survey, 53% of the students reported that they become very confident in using the components of the argumentation voice in their written essays, after two weeks of technology-enabled scaffolding in the post-task survey.

Before scaffolding in MindWare

After scaffolding in MindWare

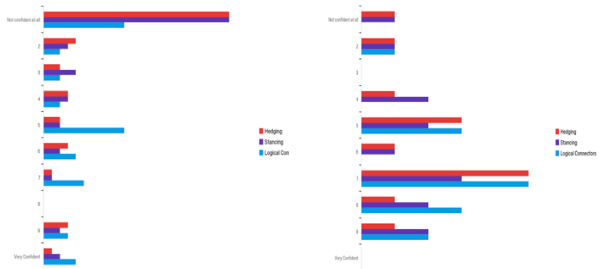

Figure 4: Confidence of the students in using the components of the argumentation voice (pre-task and post-task responses)

Overall, it seems that students' familiarity with the components of the argumentation voice in their written essays and their confidence in using such components increased after using the meta-cognitive scaffolding strategies, as enabled through MindWare.

6 Conclusion

As indicative as this early stages data overview may seem, it is neither conclusive, nor comprehensive. It is necessary to carry an extensive analysis of how the specific components of the argumentation voice have evolved or devolved across the drafts of the essays the students have submitted to MindWare. Moreover, we need to analyze the significance, if any, of the changes in the grades of the students within the experimental group, and compare the results to those of a control group of students, a course section that did not participate in the pilot study, using MindWare to scaffold aspects of written argumentation. In future work, we plan to carry out an extensive analysis to address and report on these pending aspects of our research into the interplay between the use of AI and NLP-informed learning technology, (meta)cognitive scaffolding, and learning of written scientific argumentation.

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