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When Rhetorical Logic Meets Programming: Collective Argumentative Reasoning in Problem-Solving in Programming

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ABSTRACT

Argumentation, as the generation and evaluation of arguments, is critical in our ability to reason. Computing education research has long highlighted the relation between reasoning ability and programming skills but, to our knowledge, the relation between argumentative reasoning, and particularly collective argumentative reasoning, and programming have not yet been investigated. The aim of this paper, therefore, is twofold: first, to study empirically the nature of collective argumentative reasoning in programming during problem-solving and secondly, to identify the aspects of argumentation that facilitate or obstruct collective problem-solving. To achieve these aims, through an exploratory research design, our study identifies the argumentative moves and argumentative reasoning schemes employed by expert programmers, MSc students, and first-year undergraduate students (novices) during collective problem-solving by using a protocol analysis of concurrent verbalisations. The study illustrates how collective argumentative reasoning is reflected in the discourses of these groups during problem-solving, and most importantly how argumentative moves and argumentative reasoning schemes interact and impact problem-solving. The three groups exhibited substantial differences: novices engaged in *collective monologue*, the MSc students engaged in *collective but egotistic argumentative dialogue* and the experts in *collective and altruistic argumentative dialogue*. The paper concludes by proposing a turn in educational practices that place argumentative reasoning in the center of both classroom and peer to peer discourse in programming.

CCS CONCEPTS

• **Social and professional topics → Computing education**; • **Applied computing → Collaborative learning**.

KEYWORDS

argumentation, programming, reasoning, group problem solving

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1 INTRODUCTION

Reasoning is the backbone of any problem-solving activity and as such, fostering reasoning and problem-solving have been a central focus of educators and curriculum agendas. Philosophers and education psychologists like Gagne, Dewey, and Bruner have highlighted education's central role of creating citizens who can reason and problem solve; for example, Gagne [26, p. 85] posited that *"the central point of education is to teach people to think, to use their rational powers, to become better problem solvers"*.

Reasoning, undoubtedly, involves human cognition, but human cognition is amazingly complicated and multifaceted; this is mirrored by the variety of ways that reasoning has been discussed in literature both philosophically and psychologically [64]. From a philosophical perspective, reasoning is often associated with logic stemming from the Greek word Logos which, among other things, means "opinion", "account", "reason" and "discourse"; Aristotle used the term to indicate "reasoned discourse" or "argument" in the field of rhetoric (persuasive argument) [32, p. 12]. From this perspective then, reasoning is comprised of arguments. But from a psychological perspective as well, reasoning has been linked with argumentation (the process of producing and evaluating arguments for persuading others or reaching consensus). For instance, Bruner defined reasoning skills as the process of making conjectures and conclusions from information [42].

Argumentation is central to the process of reasoning; Billig [7, p. 141] argued that *"learning to argue may be a crucial phase in learning to think"* and as such, its role in education settings is critical. In a classroom context, argumentation engages students in learning communities where reasoning, backing statements and beliefs, and evaluation of alternative possibilities become explicit by including students in an argumentative dialogue. This supports the construction of knowledge and the advancement of higher-order cognitive processes [19]. But apart from its dialogical nature, argumentation can also occur in a person's mind as a part of reflective and reasoned discourse [13]. Whatever the case, research suggests that argumentation skills do not develop naturally with only a few adults being able to produce quality arguments and developing argumentation (e.g., [9, 39, 40]). Rather argumentation skills can be trained and, in science and mathematics education particularly, argumentation has been employed extensively to facilitate students' understanding, critical thinking and conceptual development (e.g., [15, 24, 38, 44]).

Computing education literature has emphasised the relationship between reasoning skills and problem-solving in programming (e.g.,[14, 25, 28, 58]). However, to our knowledge, the nature and role of argumentation in programming has not yet been the focus of computing education research. Before we ask the question of how we should facilitate learners in programming courses to engage in argumentative discourse, we need first to understand the nature of argumentation in programming; understanding the nature of argumentation in programming will allow us to construct frameworks of argumentative dialogues that will shape the epistemological discourse that takes place in programming classrooms during both teaching instruction and peer to peer interactions.

In this study, we investigate argumentation in group problem-solving settings, firstly, because of the nature of argumentative discourse which is discussed in detail in the literature section of this paper and secondly, because programming education is committed to collaborative activities (e.g., Pair programming, Peer Instruction) to enhance students' experiences and learning. Therefore, we use the phrase collective argumentation not as a debate-type situation or as means to compete or eristic argumentation or simply convincing of one's own ideas, but rather as a process of collective contributions of reasons during which peers engage in *"dialogical argumentation, critical thinking, elaboration, and reasoning with the aim to build up a shared understanding of the issue"* [53, p. 60].The research questions of this study are the following:

(1) How is collective argumentation reflected in episodes of problem-solving of experts, MSc and first-year undergraduate students in programming?
(2) What aspects of collective argumentation influence problem-solving in programming?

To answer these questions, we focused on understanding the structural argumentation details and argumentative reasoning schemes employed by groups of experts[1], MSc and first-year undergraduate students during problem solving. The study illustrates whether and how collective argumentation is manifested in the different groups and identifies the critical aspects of collective argumentation that impact problem-solving, highlighting particularly the interaction between the argumentative moves the participants engaged with and the argumentative reasoning schemes they employed. Specifically, the three groups exhibited substantial differences: novices engaged in *collective monologue*, the MSc students engaged in *collective but egotistic argumentative dialogue* and the experts in *collective and altruistic argumentative dialogue*. The paper concludes by suggesting a turn in education practices that place argumentative reasoning in the center of both classroom and peer to peer discourse in programming.

2 THEORETICAL CONSIDERATIONS

This section sets the theoretical foundations of our work. It can principally be seen as a narrative on theoretical accounts on reasoning, argumentation and their relationship; its function is to highlight the theoretical underpinnings of our work, basically stemming from scholarly sources on argumentation and rhetorical logic, and particularly, Toulmin's model of argumentation [67], and Walton's et al.'s [74] categories of arguments.

2.1 Reasoning and Argumentation

> *We come to the full possession of our power of drawing inferences the last of all our faculties, for it is not so much a natural gift as a long and difficult art* (Charles Peirce [54, p. 45])

Charles Sanders Peirce, one of the most known American philosophers, paid particular attention to reasoning and the logic of science. He argued that a liberal education could only be achieved if the art of reasoning was a central part of it. Peirce's work on reasoning has been most influential in discussions around scientific discussion and justification, highlighting in that way that doing science is inextricably connected to *explaining, reasoning*, and *arguing* about things that go beyond reporting observations.

The relationship between reasoning and arguing, however, is not one that can easily be realised. For example, Walton [75], one of the most known authors on argumentation and informal logic, sees reasoning as taking place within frameworks and regards argumentation as one of these frameworks. However, Mercier and Sperber [46] put more emphasis on the relationship between reasoning and argumentation. In their argumentative theory of reasoning, they posit that reasoning is a fundamental social ability and has developed mainly for argumentative purposes.

The possibility that reasoning is, in fact, a social rather than simply an individual ability came to the fore a long time ago; Vygotsky [72] underlined that every function in the development of a child first appears on the social and then on an individual level.

From Toulmin et al.'s [67] perspective, reasoning is a collective and continuing human transaction:

> *Whenever an idea or a thought may come from, it can be examined and critisised rationally – by the standards of reason – only if it is put into a position where it is open to public, collective criticism... it is a way of testing and sifting ideas critically.* [67, p. 10]

Thus, from their perspective [67], reasoning is a focal activity of portraying reasons to strengthen and establish a claim. Argumentation then, they argue, is the whole process of producing claims, of questioning and backing them up by presenting reasons and challenging them, rebutting those challenges and so on.

The idea of studying reasoning and particularly informal reasoning through argumentation was brought forth from the growing evidence that thinking mirrors the processes evident in classical rhetoric more than the processes suggested by formal logic [70]. Thus, in the last decades, informal logic within argumentative settings has attracted a lot of attention in a variety of disciplines and in education as well. Particularly the fields of science and mathematics education have seen an increased interest in informal reasoning and argumentation; both philosophical and cognitive perspectives have had an impact on the justification of the centrality of argumentation and its incorporation in education settings.

The philosophical perspective emphasises that scientific disciplines advance their epistemological underpinnings not through agreement but through validating knowledge claims, debates and arguments, and it is through this process of argumentation that theories are challenged, refuted and built (Kuhn, 1962 cited in [20]). From that perspective then, science is regarded as a social construction process that employs a variety of discursive practices (e.g.,

[1]This group was comprised of experienced practitioners with more than 4 years of expertise, hereafter refer to as the experts' group.

interpreting, evaluating arguments) to progress the scientific knowledge ([27]); thus, as Lemke states *"to learn science is not to know what the last generation of scientists thinks of the world, but to find out how each new generation of scientists re-elaborates our view of the world"* (as cited in [27, p. 30]). The cognitive perspective regards argumentation as an exercise of reasoning, the externalisation of thinking which necessitates a move from the *"intra-psychological plane, and rhetorical argument, to the inter-psychological and dialogic argument"* (Vygotsky, 1978 cited in [20, p. 917]). This perspective highlights the cognitive connection between argumentation and reasoning and perceives argumentation as the reasoning process we go through to develop an argument; argument is the outcome of reasoning and thus, it can be developed both during monological (individual reasoned discourse) and dialogical discourse ([16]).

Overall, studies conducted in mathematics and science education highlight the importance of argumentation to students' reasoning, critical thinking, communicative skills, scientific literacy and language development ([31, p. 5]). But apart from these, researchers in this area showed that students' arguments reveal the grounds of their scientific ideas [44]. As such, analysing the structure of students' reasoning through arguments becomes an instrument for revealing their background beliefs and knowledge [44]. Prominent models for analysing the structure of arguments and evaluating their quality were introduced by Toulmin [68] and Walton et al. ([74]) and they have been broadly used in science and mathematics education.

2.2 Argumentation models and discourse

2.2.1 *Toulmin's model.*

> *Logic is concerned with the soundness of the claims we make—with the solidity of the grounds we produce to support them, the firmness of the backing we provide for them—or, to change the metaphor, with the sort of case we present in defence of our claims. Logic (we may say) is generalised jurisprudence.* Toulmin [68, p. 7]

Stephen Toulmin is one of the best known philosophers in the field of argumentation theory; his renowned book "The uses of Argument" [68] has been an inspirational source to researchers interested in the field of argumentation from a variety of disciplinary backgrounds. Part of his influence can be attributed to his critical position regarding the disconnection of formal logic and the practical ways of reasoning and rhetorical argument [37] and as such, his general theory and model of argumentation provides a working, practical and applicable logic.

Toulmin recognised at least three elements of an argument's structure: the data, the claim and the warrant (Figure 1).

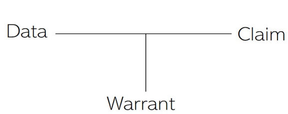

Figure 1: Basic structure of an argument

Data are the factual points of departure; they answer the question "what have you got to go on?". Data are facts, factual information we draw to ground the foundation of claims. *Claims*, are conclusions and are potentially debatable. Data and claims, taken together, are the main proof line of an argument. *Warrants* are the mental leap from data to claims and answer the question "How do you get there?". The role of a warrant is to carry the data to the questioned proposition or claim, justifying the claim as true, valid and acceptable [10]; in other words, warrants present a set of data as the grounds for the conclusions. Their goal is to demonstrate that by taking the data as a starting point, the move to the claim is legitimate.

Toulmin's argumentation model sets in the centre the notion of warrants, highlighting in that way the importance of warrants when structuring and subsequently, when analysing an argument. Given the same grounds or data or evidence, humans can generate different claims depending on the warrant chosen - the choice of warrants *"is a matter of reasoned choice informed by the perspective of the arguer and the audience"* ([67, p. 216]). Thus, analysing warrants offers a potent view of the way humans choose to frame their activities [8] and the nature of these warrants portrays whether the learner has acquired the knowledge necessary to frame these activities epistemically. While arguments themselves mirror chains of reasoning, warrants indicate what is employed or regarded as acceptable rationale to support a given claim.

2.2.2 *Walton's et al. Argumentative Schemes.*

Toulmin's model has been used for evaluating the structural quality of an argument (whether the argument's components are explicit or not). Thus, Toulmin's model cannot be employed for reconstructing the logical structure of an argument; the model describes an argument's structure but it does not indicate the argument's logical quality [49] - but analysing the quality of an argument allows the way from argument analysis to an individual's ways of reasoning. To achieve this, a turn of focus from the structural components of an argument to its semantic contents is required; the semantics of an argument is a window to individuals' reasoning and in argumentation theory is known as argumentative schemes.

These patterns or schemes emerge when we group ways of reasoning according to the structure of the semantic and logical relation between premises and conclusions. In other words, argumentative schemes are abstract structures of reasoning that group under a pattern the semantic and logical relation between premises and conclusions [44, p. 233],[69]). As such, they can be used to categorise certain patterns of reasoning and can also be used to evaluate the validity of reasoning of the arguments [49].

Walton et al.'s [73, 74] classification is the best known classification of argumentative schemes. Each argumentative scheme describes the pattern of reasoning in a form of premises and conclusions stemming from these, and has critical questions associated in order to identify possible flaws in reasoning. In the paragraphs below we describe only the argumentative patterns we identified in our study while examples are given in the discussion section.

Argument from goal. This type of argument is used when someone recognises the existence of the goal and the necessary or sufficient conditions needed to bring about this goal ([74]). The general structure of such an argument is given below but for the rest of the schemes we have omitted this information.

Argument from goal

Premise 1: I have a goal G
Premise 2: Carrying out this action A is a means to realise G
Conclusion: Therefore, I ought to (practically speaking) carry out this action A.

Figure 2: Argument from goal

Argument from cause to effect. The argument from cause to effect is usually employed when individuals connect, correlate two events; it demonstrates the effect that is the result of a given action or event and states that generally, events of this type cause events of another type[74].

Argument from example. This type of argument is employed when individuals make use of an example to support a claim through generalisation.

Argument from sign. The argument from sign is used when two or more things are closely related so that the truth or the presence of one of them suggests the truth or presence of the other. This type of argument is closely related to abduction a form of reasoning focusing on hypothesis production and best explanation ([74]).

Argument from analogy. The argument of analogy is one of the fundamental forms of argumentation in general and is the foundation of all case-based reasoning, in which argumentation is based on comparisons between cases in terms of similarities and differences ([74]).

Argument from consequences. In arguments from consequences, the interlocutor's goal is to evaluate an action and whether to pursue it or not based on the potential consequences.

Source based arguments. Source based arguments are arguments based on an external authoritative source, like a person, a group, or a book and similar sources to bear out the conclusion [73]. The following argumentative schemes belonging to this category were identified in this study:

- argument from popular practice: these arguments are based on the acceptability of a practice in a subject domain from a group or community of people who are familiar with this domain.
- argument from popular opinion: these arguments are based on the joint acceptance of an action, opinion, from a group of people.
- argument from position to know: these arguments are based on the acceptance of an opinion as true or false as this was supported by a knowledgeable source in the corresponding domain.

It is the aim of this study to identify how the argumentative schemes employed by expert programmers, MSc and novice students during problem solving may contribute to shared understanding and problem solving. However, as Felton and Kuhn [22] highlight, discourse is fundamental to argument construction and thus, the most appropriate way to explore it, is within the contexts of discourse.

2.2.3 Discourse and Argumentation. The importance of classroom discourse on students' understanding and knowledge construction has long been highlighted by educators and researchers. Vygotsky's perspectives on the importance of social interaction for language and cognitive development has been influential in studying classroom and teacher or peer to peer discourse. Although orchestrating teacher and peer to peer discourse and collaboration have been emphasised, successfully organising such collaborative communicative interactions is challenging.

Chi [12] suggested that what is important in collaborative learning, is the interaction processes; in other words, the transactive processes (e.g., [66, 77]). Research studies on the role of transactive statements on students' learning have developed early in 1980s and have highlighted their role in student' scientific reasoning (e.g., [2]), performance on an exam (e.g., [33]) and problem engagement and debugging in programming (e.g., [51]). Berkowitz and Gibbs [6, p. 402] defined transactive discussion as "reasoning that operates on the reasoning of another" and thus, indicates the way that interlocutors "build on, relate to, and refer to" ([53, p. 62]) each others claims; they [6] provided a classification of transactive statements (e.g., critique) which include argumentative moves and thus, transactive process is regarded as an advance form of argumentation ([59]).

2.2.4 Bringing everything together. In framing this work, we have used many familiar words in order to explore the area of argumentation. We fix now on specific meanings for words and phrases used in the rest of the paper.

- We use *argument* as the outcome of reasoning; an argument is an artefact.
- *Reasoning* is "the process of inferring conclusions from statements" ([75, p. 402]); thus, reasoning is employed in an argument and arguments express some of our reasoning[75].
- The structure of the reasons and their relationship to the claim are captured by an *argumentative scheme* of which Walton et al. define many different kinds.
- We use *argumentation* and *argumentative reasoning* interchangeably and these represent the reasoning process of developing and evaluating an argument ([67]). This process can take place in during monological and dialogical discourse. In this paper, we focus on the latter and particularly on argumentation as a collective or collaborative activity carried out in a group setting such as might be found in a computing classroom or work-place.
- *Collective argumentation*, thus, is a process of collective contributions of reasons during which peers engage in *"dialogical argumentation with the aim to build up a shared understanding* [53, p. 60]. The discussion taking place during argumentation may match the reader's *colloquial* understanding of the word argument - but in this context, an argument is an artefact, and argumentation is the process of identifying and honing that artefact. We should say of a warring couple not that they are having an argument, but that they are having a (probably not very productive) argumentation.

- Participating voices in collective argumentation use a range of *argumentative moves* to move the argumentation process forward. Argumentative moves are statements that may propose the reasons and claim for an argument, or challenge a given argument by proposing a counterargument, or question aspects of the argumentative scheme employed, or build on and advance a given argument by improving the detail of the reasons or claim.

Using all of this terminology, analysing deeply collective argumentative reasoning in problem-solving contexts entails an understanding of the semantics and logical quality of the arguments, namely, the argumentative schemes employed, and as Andrews [1, p. 110] noted, the "choreography of argument", highlighting argumentation's dialectical nature and its interactive transactions in speech. Argumentative moves characterise these interactive aspects of argumentation and facilitate knowledge acquisition and problem solving ([76]). In the Methodology section below, we explain how we employed these perspectives to study collective argumentative reasoning in programming discourse.

3 METHODOLOGY

The study adopts an exploratory research design. In contrast to confirmatory research designs, which proceed from the hypotheses to the test of these hypotheses, the aim in exploratory designs is to gain new insights of a previously unexplored phenomenon and determine what novel hypotheses might be generated from it and can further be tested with confirmatory research studies ([29]).

In the following sub-sections, we describe in detail the research design.

3.1 Participants

Three groups at different levels of expertise were considered in this study: experts, MSc, and first-year undergraduate students (novices). Each group consisted of four members.

The experts' group was comprised of four software engineers with 5.5 average years of expertise. All participants worked in the same company but two of them worked in different teams. The MSc and novice students' groups were each comprised of four students studying Computing. The novice students had successfully completed an introductory computing course taught in Python and were among the students with the highest scores. We selected these students on purpose, as we wanted students to have a very good understanding of programming. This was because we did not want any findings to depend on significant students' gaps in knowledge and for increasing the chances of having richer examples of argumentative discourse. The study was advertised in students' forums and ethical approval was granted by our university. Prior to the study, all participants were informed about the aims of the study and signed a consent form.

3.2 Research process

The following process was repeated three times in total, once for each group, and was held on Zoom and was video recorded. The participants were asked to work together to solve the programming task presented below and were given explicit guidelines of what was expected of them: they were specifically asked to think out loud as much as possible, not hesitate to state their opinion, suggest alternatives or kindly pose counterarguments and raise concerns about a suggested approach. All groups were given 60 minutes to complete the programming task.

3.3 Data Analysis

The data were analysed by protocol analysis of concurrent verbalisation, a think-aloud method for discerning the participants' cognitive processes. Thus, the data were recorded with the participants' consent and transcribed in full. The emphasis of the analysis was the content of speech and sequence of speech turns. To investigate how collective argumentative reasoning was manifested in the discourse of our groups, we analysed the transcripts in respect to the argumentative moves the participants engaged with and the argumentative reasoning schemes they employed.

To analyse the verbal data, deductive code analysis was used at two levels of analysis, micro and macro level analysis. The data analysis was performed in NVivo. Below, we describe in detail the steps we followed:

Identification of episodes of argumentation. Following similar guidelines with Chin and Osborne [13] and Dede [17], the transcript of each group was segmented into argumentative episodes; these are sequences of arguments related to an idea put forward. In these episodes, the participants take turns by making argumentative or non- argumentative moves reflected as speech acts ([13]). By segmenting the transcripts into argumentative episodes facilitated the process of coding and the identification of claims, and other argumentative moves the participants employed to support their arguments. Each utterance (turn in speech) in an argumentative episode was coded as described below. The first and the third author worked together before the start of the coding process to segment the transcripts; thus, we do not report the Cohen's kappa for this phase.

Coding utterances in each argumentative episode. For each argumentative episode we performed a micro and macro analysis to understand how collective argumentative reasoning is manifested in the three groups and the way it impacts collective problem solving.

The aim of the *macro analysis* was to identify the argumentative moves the participants engaged with (Table 1). To this end, we employed the categories suggested by Weinberger and Fischer ([76]) which include the following argumentative moves: an argument, a counter-argument, and integration (Table 1). The argumentative moves presented in Table 1 comprised our pre-defined list of codes.

Each utterance in an argumentative episode was coded in one or more of these categories (for instance, an integration statement may advance a preceding argument by extending it with further claims). The first author reviewed and coded the entire transcripts while the third author coded half of them for each group. When both researchers coded half of the transcripts, Cohen's kappa was calculated and was .95, $p < .05$.

The aim of the *micro analysis* was to understand how the participants chose to logically structure their arguments (the semantics of the arguments) and particularly, the type of argumentative reasoning schemes they employed to justify their claims. To do this, we first identified the warrants (Toulmin's model) the participants employed to justify their claims. In focusing on the utterances where experts and students made a claim, the transcription text was examined both forwards and backwards in order to identify the warrants. Identifying the warrants was important to categorise the arguments to Walton's et al.'s argumentation schemes ([44]). The Cohen's kappa was calculated as before and was .85, $p < .05$. Thus, we categorised each argument to one or more of the argumentative schemes suggested by Walton et al. [74] depending on the warrants and the underlying premises that supported the arguments made. When premises were not evident, the argument was re-constructed so that any missing premises are identified (e.g., [38, 44]). For this reason, the first and third authors worked together to reconstruct and categorise the arguments in half of the transcripts with an extensive discussion taking place between the two researchers. The first author coded the rest of the transcripts with the third author reviewing them and agreeing with all of them.

Identify and categorise uses and errors in Argumentative Schemes. Additionally, we were interested in exploring the occasions of use of the argumentative schemes within problem-solving in programming and potential errors in their use. Thus, for each argumentative scheme, we noted in a list the interlocutor's intentions of use and the identified errors in employing this scheme. This phase was done in parallel with the previous, thus, the same procedure was followed in terms of the agreement between the two researchers.

Table 1: Argumentative moves at macro-level of analysis

Categories of Moves	Description
Argument	Statement put forward in favor of a specific proposition
Counter-Argument	An argument opposing a preceding argument, favoring an opposite claim
Integration	Statement that aims to balance and to advance a preceding argument and counterargument
Non-argumentative moves	Questions, justifications, coordinating moves, and meta-statements on argumentation

3.4 Materials

For choosing an appropriate task for the aims of this research, we decided to give a problem that the students and the experts would find challenging to solve. We mirror, therefore, Schoenfeld's [61, p. 41] definition of a problem: *"a problem is only a problem, if you do not know how to go about solving it. A problem that has no surprises in store, and can be solved comfortably by routine or familiar procedures (no matter how difficult!) it is an exercise"*. Understanding, therefore, the role of collective argumentative reasoning in problem solving, entails engaging the participants in a situation of doubt and puzzlement, with a problem which no matter how "slight and commonplace" [18][p. 9], confounds and challenges the mind.

The following task was selected as the problem-solving task:

Problem

Given a finite set of coins C, and a positive value N, write a program that calculates in how many ways can we pay the value N precisely using only the coins in C?

Figure 3: Problem Task

4 RESULTS

As we highlighted in the methodology section, we followed a four step process for analysing the data: a. identify the argumentative episodes b. coding utterances in argumentative episodes by performing both i. a micro-analyses and ii. macro analysis c. categorise uses and errors in argumentative schemes. This section, thus, reports on each of these processes.

4.1 Argumentative Episodes

The first step for analysing the data was to segment the transcripts in argumentative episodes. Table 2 depicts the number of argumentative episodes for each group as well as the percentage of completion of the task (how close to solving the problem) in the same amount of time (60 minutes).

Table 2: Argumentative episodes

	Experts	MSc	Novices
Number of argumentative episodes	7	12	21
Mean length (number of speech turns) of episodes	21	14	10
Percentage of task completion in 60 minutes	85%	60%	30%

The table depicts that the least amount of argumentative episodes were identified in the experts' discourse, 7 in total, whereas novice students produced 21 different argumentative episodes in the same amount of time. None of the groups manage to fully complete the task within an hour, so in Table 2, we presented the percentage of task completion for each group as it was jointly decided from the researchers. As it is evident, the experts' group achieved the greatest percentage of task completion, followed by the MSc students and then the novices.

4.2 Macro-Analysis

Table 3 depicts the percentage of the argumentative moves (to the total number of speech turns) made by each group.

As it is evident, in the same amount of time, experts produced the highest percentage of arguments (32%), while the MSc students produced the highest percentage of counter-arguments. Additionally, experts most frequently engage in integration moves (35%), than both the other two groups. Novice students' discourse was restricted to the production of arguments and non-argumentative moves (73%) whereas argumentative moves like integration, counter-arguments

Table 3: Argumentative Moves

Argumentative Move	Experts	MSc	Novices
Argument	32%	13%	19%
Counter-Argument	4%	15%	2%
Integration	35%	16%	10%
Non-argumentative moves	52%	57%	73%

were rarely employed in their discourse. The MSc student group discourse included a fair amount of counter-arguments in comparison to what was evident in the other two groups. We need to highlight at this point that an integration move may also be coded as an argument as it may advance a previous claim with a further claim as it was mostly evident in the experts' account. That is the reason why the percentages in the table do not add up to 100.

4.3 Micro-Analysis

To understand the underlying reasoning that supported the groups' arguments, we performed a micro-analysis with the aim to identify the argumentative reasoning schemes employed by each group.

We first identified the warrants (how the participants choose to ground their claims) employed by each group. Table 4 depicts the percentage of claims made (to the total number of speech turns) and the percentage of these that were explicitly justified, meaning that the interlocutor provided a warrant that guaranteed the claim's validity.

Table 4: Type of claims

Type of claims	Description	Experts	MSc	Novices
Simple claim or counter-claim	Claim without a warrant	4%	12%	5%
Grounded claim	Claim with warrants (this does not guarantee that the warrant is reasonable)	32%	16%	16%

The table depicts that all groups provided justifications for the claims they made with novices and experts providing more than did the MSc students. However, it is important to highlight that this is because the MSc students engaged more in producing counter-arguments that were left unsupported which was not evident in the other two groups. It is also important to underline that the fact that a claim is supported by a warrant does not mean that the warrant is correct. On the contrary, it is through the analysis of the semantics of the warrants that problems in students' understandings can be revealed, something we demonstrate in the discussion section and justifies the aim of the micro-analysis we conducted below.

After that, we categorised each argument to one or more argumentative schemes depending on the warrant and the underlying premises supported the claims. Table 5 depicts the occurrences of the most frequent argumentative schemes employed by each group.

All three groups used more often the argumentative scheme named *argument from goal* which is a type of argument used when

Table 5: Frequency of Argumentative schemes per group

Type of schemes	Experts	MSc	Novices
Argument from goal	16%	10%	10%
Argument from sign or evidence	11%	4%	1%
Argument from example	10%	9%	1%
Argument from cause to effect	8%	7%	4%
Argument from popular practice	6%	3%	1%
Argument from consequences	3%	1%	0%
Argument from popular opinion	2%	0%	0%
Argument from analogy	0%	2%	1%
Argument from position to know	0%	0%	2%
Unsorted	0%	7%	2%

the interlocutor has identified a goal and the steps that are going to realise that goal. The experts quite often used *arguments from sign or evidence* while both experts and MSc students employed *arguments from example* more often than the novices. The *argument from cause to effect* was also identified in the accounts of all groups while *argument from popular practice* was used more often by the experts' group. The *argument from consequences* was only evident in the experts' and MSc students group while *the argument from analogy* was evident only in the MSc and novice students' groups. Finally, the *argument from popular opinion* was only evident in the experts' discourse while the *argument from other position to know* was made only by the novice group as they were the only group that used online resources to solve some parts of the problem.

4.4 Uses and Errors in Argumentative Schemes

The final step in our analysis (in practice, this step was executed in parallel with the above analysis but we report it as a final step to indicate the sequence in the way we report our findings) was to identify the reasons why the participants employed the argumentative schemes reported in Table 5 and any errors in the way they were employed. Table 6 presents these findings (discussed in section 5.1.2).

5 DISCUSSION

This section discusses the results of our study with regards to our two research questions presented in the introduction section.

Table 6: Summary of argumentative schemes and how they were employed

Scheme	When it was used	Errors in use
Argument from goal	when a goal has been identified and certain actions are suggested to realise the goal	a. wrong goal b. wrong set of actions
Argument from example	a. to better understand the problem and identify a set of actions b. to justify a claim	none identified
Argument from cause and effect	to explain the effects of a certain action	acceptance of an unwanted effect
Argument from sign	usually employed before an argument from a goal, as a form of hypothesis to speculate for a potential action	arbitrary speculation
Argument from popular practice	when a common practice in programming was judged suitable to the particular problem case	none identified
Argument from popular opinion	when an argument was explicitly based on the group's consensus	none identified
Argument from Consequences	to evaluate the consequences of a proposed solution	none identified
Argument from Analogy	when similarities in two cases were identified	wrong application of analogy
Argument from position to know	ground a claim on an external source	none identified

5.1 How is collective argumentation reflected in episodes of problem-solving of experts, MSc and first-year undergraduate students in programming?

The first research question of our study aimed to shed light on the nature of collective argumentative reasoning during problem-solving and to highlight the differences between groups at various levels of expertise.

5.1.1 Macro-analysis of argumentation. The first level of our analysis aimed to understand the way that argumentative moves take place in groups of different levels of expertise during problem-solving. Having first segmented the data transcripts into argumentative episodes, we focused on identifying the types of argumentative moves the groups employed and their frequency. All three groups engaged in the generation of claims or counter-claims made in the form of steps that the group should follow to solve the problem and their underlying rationale that supported this claim (warrant). The following example stems from the experts' account:

"Yeah. I mean, if we want to find the unique ways that we can create the value of N, then would you have to, let's say start from the second, or take the first value in the list, and then look at all the potential remaining combinations in the list with that value first. That would get into N."

The three groups showed differences regarding the frequency of the argumentative moves they employed which hindered or facilitated the problem-solving process.

The experts' discourse centred around the generation of a well-supported argument (most of their arguments were grounded, Table 4) and their ability to evaluate and integrate another person's claim into their own reasoning and progress this reasoning further (integrative moves). Making these argumentative moves was critical for building a shared understanding of the problem and progressing collective reasoning to reach a solution. A few cases of counter-arguments were made, exactly in cases where the provided argument was not well-justified. Thus, counter-arguments were used only when necessary which demonstrates experts' approach of first considering a suggested argument and its validity deeply, and building on it (integrative) to advance shared reasoning before refuting it. Voss and Means [70] state that a highly competent reasoner, among other things, accepts a claim by restructuring it. Below we provide an example of the experts' accounts:

Integration:

Speaker1: *And then you could potentially look for specific values in the list.*

Speaker2: *So and then look to validate that each um possible combination is present in the uh is present in the set of C? Yeah?*

Speaker1: *Yeah*

Speaker2:*Uh and for each one that is, is present and effectively to account.*

Speaker1:*Yeah. And potentially, instead of going from the sum, we could start from the total and subtract. Um that might be quicker.*

Speaker2:*To calculate the cost spaces. Yeah. Okay.*

In comparison with the experts, the MSc students argumentative moves included many counter-arguments, and less integrative moves. Whereas producing counter-arguments is a skill of high reasoners [70], these were quite often made at the expense of shared understanding especially when counter-arguments were left ungrounded. This suggests that the MSc students were too focused on their own reasoning, they were quick on disregarding their peers' arguments by contradicting it with their own claim and by providing justifications that mostly supported their rationale instead of refuting their peer's claim, until eventually, someone had to back up. Their argumentative dialogue, thus, was fuelled with knowledge counter-claims that were not well justified (Table 4). That explains the lower percentage of integrative moves in comparison with the experts, as instead of focusing on understanding their peers' argument and advancing it or asking further questions, they were hastily rejecting it. An example is demonstrated below:

<u>Counter-Arguments</u>

Speaker 1 - Claim: *"What I was saying is that, you know, you sort the coins by value and you get the biggest coin, which obviously does not exceed N, and then basically going forward to the smallest, you start adding. And if it does not exceed N, you add one. You add the next, you add the next, until you see that it surpasses N. If it surpasses N, you skip this one and move on to the next."*

Speaker 2: *No, It's a greedy algorithm*

Speaker 1: *No, it's not*

Speaker 2: *It is I think*

Speaker 1: *My way makes much more sense - maybe there are others too*

Finally, the undergraduate students produced the fewest argumentative moves which were constrained to the generation of claims without consideration of advancing, questioning or challenging their peers reasoning further. This explains the large number of argumentative episodes they produced (Table 1) as their ideas changed focus frequently since their claims were underdeveloped (almost 10 occurrences in each episode) and were not advanced or challenged by the other members. In contrast, experts focused on developing concrete ideas (7 in total), and expanding the discussion on each idea until it was resolved (21 statements per episode). Thus, collective argumentative reasoning and problem-solving were hindered in the novice group. As Sperber and Mercier [47, p. 60] mention: *"For communication to be stable, it has to benefit both senders and receivers; otherwise they would stop sending or stop receiving, putting an end to communication itself"*.

Overall, the macro analysis depicts that collaborative problem-solving within this domain-specific context was facilitated by the group's ability to employ a variety of argumentative moves. As it was evident, the experts' group produced argumentative moves that focus on generating well-grounded arguments and evaluating and advancing their peer's reasoning, while the MSc students focused mostly on contradicting their peer's reasoning with some occasions of integration. Finally, the novices did not manage to engage in a collective argumentative dialogue and focused on producing arguments without advancing or refuting their peers' reasoning; in other words, collective argumentative reasoning was not evident. These findings, although restricted by the small number of the groups, highlight that collective problem solving is not only about making claims about potential steps to solve the problem; it is also about the communicative argumentative interactions, the way the members of a group take turns in the contribution to reasons, by elaborating, justifying, evaluating and advancing their own and their peers' reasoning.

5.1.2 Microanalysis of argumentation - Argumentative Schemes. The micro-level analysis aimed at understanding the semantic contexts of an argument, the underlying reasoning employed to formulate an argument. To this end, we classified the participants' arguments according to Walton's et al.'s argumentation schemes [74]. In the following paragraphs, we discuss the argumentative schemes found during the analysis.

Argument from goal. Experts, master and novice students used this type of argument most frequently, something expected as solving a problem requires identifying goals or sub-problems and the actions that realise these goals ([5]). However, whereas experts employed this argumentative scheme correctly, we identified two sources of errors in novice students' reasoning: a. identifying a wrong goal b. employing actions that do not realise the goal (Table 6).

The following example is from the experts' accounts:

"Yeah, … as the first step to check in the collection for any values that were bigger than N and then couldn't possibly add up to make that."

A corresponding example from the novice students' accounts is the following:

"Um I have an idea, but I'm not sure if it's bad. But if so maybe we could build on it, we might. So essentially, we have a nested for loop. And first going to go through each element of, of like the rest, and we add like the successive elements, but not the ones before them. So and for each of the times you do that, become a possible way to get there."

In this example, we can see that although the goal is right, the means to carry out the goal is fallible as combinations can be created with elements that are not successive.

Argument from cause to effect. Experts and MSc students used these type of argumentative scheme more frequently than the novices.This argument was employed when the groups discussed the result an action would have had on their solution. The only error we identified in novice students' accounts was accepting an effect as a desirable one whereas they should have not.

Below is an argument from the experts' group that falls in this category:

Speaker 1:*So, the result of that then is that we've got a set of a set of coins that are less than or equal to the value of N.*

Speaker 2: *yeah, potentially create a smaller array*

And a same argument made by the novice students which is fallible:

"That could work. But I mean that could work. Like what I'm picturing is that if you say well sum is not equal to N, then you will run your for loop once for example, and then you run run through the list and you're gonna get one combination."

In this example, the student argues that the condition in the for loop should be "sum not equal to N", and once the sum equals N, and thus, a solution has been found, the iteration should stop. The student here thinks that this is a wanted effect, to stop the iteration once a solution is found, but this would have prevented them for finding other solutions.

Argument from example. Both experts and MSc students made use of this type of argumentative scheme for two main reasons: a. to justify the validity of a claim b. to better understand the problem and move on to the generation of a claim. This type of argument was not used as often in the novices' discourse.

The first example below is from the experts' account:

"Like, I think, ... this is probably quite a good example, right, when N= 7 and 5,2 and N=3 and 2,1, right? .... so, joining the 2 together, right and adding them, right? Because they're really the really easy one then to work out is that if you add them all together, then do they equal N? And then that's your that's one set of counts done."

Another example comes from the MSc students:

"In this way, we are going to miss some cases. Let's see, if you have 5,2,2,1, right? and that is your solution but there is one more 1 in the set, right? this 1 is another solution with the same 5,2,2 we had before".

Argument from sign. This type of argument was evident mostly in the experts group in a form of a tentative suggestion towards the pursue of a given goal. Novices made limited use of this type of argument and one of the errors was the generation of an arbitrary hypothesis not based on actual signs.

The example below is from the experts' account:

Speaker 1: *if the set is an array, then I guess you can, we can have like 2 we can have like 2 loops, for instance.*

Speaker 2: *Okay, I think I think I see what you mean ... So so yeah, there's going to be some kind of iteration of the array, for sure. Right*

A corresponding example from the novice students is given below:

Um I feel like we're not going to move through the list just once, it's going to be a couple times. So I don't think one is enough. I feel like there should be a while loop. Well, am I not getting a condition for the for loop. Because I don't see what condition we can code on it.

The student in this case makes an arbitrary hypothesis since there is no data to support it other than her difficulty to determine the number of iterations.

Argument from analogy. This type of argument was evident in the MSc and novice students' accounts. We did expect to find more evidence of this type of argument in all our groups' account, since the literature in programming has highlighted the relationship between analogical reasoning and programming (e.g., [14]). One potential reason for this may be the nature of our problem. In all of the occurrences of this scheme, students drew from their mathematics knowledge to find similarities between mathematical formulas for calculating the number of combinations and the corresponding problem. However,the MSc students did not continue this line of thought as these arguments were made as counter-arguments which were never justified or questioned by another student but were immediately rejected by the other members. In comparison, the novice students tried to find a corresponding solution online (argument from position to know demonstrated below). An example from the MSc students is given below:

Speaker 1: *There is a formula in maths we can use to calculate the number of combinations, something like c(k)=N, not sure*

Speaker 2: *Let's not bring maths into this*

Argument from consequences. The argument from consequences was employed by the experts and MSc students when they evaluated the effectiveness of a claim they made and whether they should proceed with a course of action. This type of argument was not evident in the accounts of the novice group. The following quotes are from the experts' account where one of the experts suggests a potential step but then judges that this is not the most effective way since a brute force implementation would not have been efficient (there is a hidden premise supporting this argument which can easily be reconstructed. e.g., "A brute force implementation is not a good practice as it requires a lot of processing time"):

I guess, if you have an array, if the set is an array, then I guess you can, we can have like 2 we can have like 2 loops, for instance. And then for each index, we check whether index i fits directly into, like the given target, or like can be added to an index J to create the target. And if it does, then, obviously, that's like a brute force...So it's probably not even that great.

Source based arguments. In this study, we identified three argumentative schemes belonging to this category:

The first scheme, "argument from popular practice", was evident in all groups with higher frequency of use in the experts' group. This type of argument was used when the participants made a claim based on common practices in programming, like the use of patterns or plans to solve a particular part of the problem. The following is an example from the experts' account in which one of the members suggests to create a function for a particular part of their code:

"So I think I think there's duplication going on here...So I think we could probably reuse this, right, this logic. If this was a function, we could reuse that function don't we? "

The "argument from popular opinion" was evident only in the experts' discourse when one of the members was explicitly basing his/her argument on the other members' confirmation. The following is a corresponding example:

"And then and we check we check this again, right? Okay. Okay. And so everything is either great to or less than. I see you all nodding so I'd take this as a yes."

The last argumentative scheme, "argument from position to know", was employed only by the novice group as they were the only group that looked for a solution online, regarding this source as a knowledgeable source. Below, we present an example:

"Oh, uh I have one (online code) that prints all sub lists of a list in Python. Um so if you give it a list of 1, 2, 3, it's going to print everything starting from one district wide and up to 1, 2, 3. So it prints all different sizes...It works and it gets all the sub lists."

All in all, experts and MSc students did not limit themselves to using only specific argumentative schemes (e.g., argument from goals) as did the novices. Whereas we did not notice any fallible ways in the experts' use of these argumentative schemes, we highlighted some problems in the way that the other groups made use of these arguments (Table 6).

5.2 What aspects of collective argumentation influence problem-solving in programming?

From the macro and micro analysis presented above, certain aspects of collective argumentative reasoning and how the influence a group's capacity to reason collectively and problem-solve become evident. These aspects are the following:

- the capacity of the individuals to engage in argumentative moves and back up their claims and counter-claims
- the capacity of the individuals to employ a variety of argumentative reasoning schemes correctly to move forward collective reasoning and the problem-solving process

Regarding the first aspect, the experts' group produced argumentative moves that included mostly claims and integrative moves, which encouraged collective reasoning, problem-solving, and a deeper understanding and organisation of the problem space (e.g.,[3]). On the contrary, the novice group, although competent in programming, demonstrated poor engagement in argumentative moves, they did not consider their fellow's ideas critically nor advanced their reasoning and their dialogue was mostly acquiescent which prohibited the reasoning process, problem-solving, and understanding of the problem. The MSc students used many counter-arguments in unnecessary conditions and mostly in unjustified ways which caused delays, frustration in the team and prohibited shared understanding when explanations were not given. These aspects highlight the importance of the "collective exploration of the dialogical space of the solutions" [53, p. 60] during collaborative problem-solving and align with studies on experts' and novices' problem-solving strategies. In their paper, Nokes-Mallach et al. [52] point out that experts of the same domain organise their knowledge in similar ways which facilitates success in collective problem solving for two reasons. First, it promotes fast problem identification as experts can quickly encode characteristics of problems by using goal-relevant representations and second, shared knowledge organisation enhances the possibility of elaboration during collective problem solving. The latter point suggests that information generated by one expert can effectively be used as a cue (cross-cuing) for another expert to generate additional information ([52]). This observation aligns well with our finding of how quick the experts were on integrating their peers' reasoning and advancing it further. Nonetheless, although knowledge organisation, undoubtedly, is a critical factor for successful group problem solving, communicative interactions are also important. For instance, an over-emphasis to agreement at the expense of information elaboration, has been shown to obstruct shared reasoning and collective problem solving ([36]). This was the case with our novice group where their discourse was mostly acquiescent instead of asking for further elaboration or questioning their peers' claims.

The latter aspect, argumentative schemes, demonstrates that although argumentative schemes are general in the sense that they can be used in different contexts, applying them in domain-specific contexts needs training and expertise. Although argumentation skills develop earlier in one's life, students need to contextualise these to the corresponding domains to which they are applied. Toulmin argued that *"While students have previous experience with arguments in their everyday life, each professional field imposes its own set of norms for argumentation"* ([23, p. 530]). For example, apart from the errors in use of some of these arguments, novices made less use of the scheme "argument from example", "argument from cause and effect", "argument from popular practice", and "argument from sign", which indicates that they have not yet contextualised the way that these scheme of reasoning can be used during problem-solving in programming and how they can be challenged. The "argument from example" really helped the experts and the MSc students to concretise a vague situation and explain their reasoning to their peers. Similarly, the "argument from cause and effect" helped both experts and MSc students to communicate the effects of a certain type of action and decide together whether it was something worth pursuing or not; thus, it facilitated collective decision making. The "argument from sign", a type of abductive reasoning, facilitated the generation of tentative claims that served as cues for the other members of the experts group, to capitalise on their peers' reasoning and advance it further. An important point to be made here is that although it may seem that the focus of argumentative scheme is on reasoning at the individual level, this should not be interpreted as such. The validity of an argumentative scheme depends on the communicative interactions between the members of the group who are responsible to evaluate the argument and challenge it, and advance it appropriately. This observation links back to the first aspect presented in the above paragraph, highlighting in this way the relationship between argumentative moves and argumentative schemes in collective argumentative reasoning.

Reflecting on the findings reported above, we can characterise novice's dialogue in collective problem solving as a form of *collective monologue*, mirroring Piaget's [55] ideas about language development. Piaget used the phrase collective monologue to describe situations where children are found to be having conversations but in fact, are making individual monologues as a result of a child's egocentrism – in other words, children are making contributions in turn [50] and do not ask for evidence to support a hypothesis made. This mirrors perfectly our observations on the novices' dialogue and shared reasoning during collaborative problem-solving. For Piaget, it is the ability to decentrate (consider another person's view), that sits at the centre of argumentative reasoning. It is because argumentative skills necessitate distancing oneself from one's own discourse and considering it as one of many alternatives. It also

Table 7: Summary of differences between different levels of expertise in the current study

Category	Nature	Argumentative Moves	Argumentative Schemes most frequently used	Argumentative Schemes unique to each category
1 Collective Monologue (novices)	Non-Argumentative	Mostly individual arguments, few occurrences of integration, and counter-arguments	From Goal	From Source
2. Collective but Egotistic (MSc)	Argumentative dialogue to persuade, convince and build consensus	Arguments and Counter-arguments evident, not always supported, occurrences of integration	From Goal, Example, Cause and Effect	
3 Collective and Altruistic (experts)	Argumentative dialogue to build consensus	Arguments and integration highly evident – counter-arguments only when necessary and fully supported	From Goal, Example, Cause and Effect	From Popular Opinion

necessitates relating one's point of view to that of others [50], something which was perfectly demonstrated in the experts' discourse. Thus, this group engaged in collective and altruistic argumentative dialogue. The aim of the collective argumentative reasoning was to reach consensus and build shared reasoning to problem solve effectively and not just to persuade on the validity of one's argument which was mostly the case in the group of MSc students. The MSc students did engage in argumentative dialogue but this was fuelled with a demonstration of knowledge claims in the form of counter-arguments which were not well supported. In other words, MSc students dialogue was collective but egotistic in nature.

The above observations align with the two communicative goals of argumentation: arguing to convince and arguing to establish consensus ([11, 41]). The former aims to weaken opposing arguments and convince opponents to shift their positions [11]. This was evident in the case of the MSc students. The latter, is a negotiation process, that focuses on understanding each other's positions, evaluate them, re-consider them, and advance them correspondingly. This latter point is what Noroozi et al. [53] calls collaborative argumentation which was clearly evident in the experts' discourse. Table 7 summarises the findings reported above for each group and suggests that collective argumentative reasoning is central to problem-solving and knowledge construction. Being able to argue and discuss alternative points of view are important skills that students need to develop for shared reasoning during collective problem-solving, to refine conceptual understanding and co-construct knowledge, and as a fundamental skill for their future careers.

6 LIMITATIONS

The current study shares an explanatory limitation with all qualitative studies: basically it is heuristic, and thus, cannot guarantee any generalisations. Therefore, since the study only included one group per expertise level and saturation has not been met, further research should be conducted to explore how collective argumentative reasoning is developed in programming. Another point that needs to be highlighted is that this study has adapted a specific definition of problem solving, mentioned in the methodology section, and thus, researchers interested in extending or repeating this study should be careful to reflect on this definition. Additionally, the study has been conducted via Zoom, although we do not believe that this poses threats to the research design as both the students and the expert practitioners, due to Covid restrictions, had familiarised themselves with communicating and working via Zoom or Microsoft Teams. Finally, regarding the synthesis of the groups, it is possible that students who are not affiliated with each other may feel intimidated to participate in the discussions. This was not the case in our study as most of the students in each group were acquainted and had experienced working in pairs (pre-requisited in their training).

Overall, despite the exploratory nature of this study, we can perhaps say that the analysis of these three case studies can identify more precisely than before, phenomena in the field of computing education for further theorising and research about the role of collective argumentative reasoning in problem solving settings, and how these may be important in how students learn about programming and acquire skills in reasoning about it.

7 IMPLICATIONS AND CONCLUSION

> *"What reason does, is help us justify our beliefs and actions to others, convince them through argumentation, and evaluate the justifications and arguments that others address to us"* (Mercier and Sperber, [48][p. book summary)

The question of how we, as instructors and researchers, can advance students' reasoning is an enduring one; studies in educational psychology support the view that developing an apprenticeship in reasoning is *"an induction into ways with words and ways of thinking achieved through dialogue"* [57, p. 20], highlighting in this way the reciprocal relationship between cognition and dialogical discourse. Seeing reasoning as a social and collective activity reflects Vygotsky's socio-cultural theory of learning in which peer collaboration mediated by language leads to knowledge construction [27] and higher thinking skills through the internalisation of socially mediated interactions and argumentative dialogues in one's own cognition [65]. In a much stronger point of view of the role of language and socialisation in reasoning, Mercier and Sperber, in their book "The Enigma of Reason", posit that the main function of reasoning is argumentation [48, p. 8]. They note that *"By giving reasons to explain and justify themselves people indicate what motivated and, in their eyes, justifies their ideas and actions"*.

In this study, we focused on collective argumentative reasoning as a means to *"transform individual thought into collective thought and action"* [45, p. 125] and as *"a discourse through which reasoning flows"* [71, p. 345]. Emphasising the dialogical dimension of argumentation led us to highlight the importance of the interaction between argumentative moves and argumentative schemes of reasoning to shared understanding of the problem-solving space and solutions. Our results reveal that collective argumentative reasoning was only evident in the discourse of the MSc and experts' group but it had different nature – the experts' engaged in *collective and altruistic argumentative dialogue* with the aim of reaching consensus; thus, they engaged in argumentative moves that focused on understanding deeply and advancing their peer's reasoning, making counter-arguments only when it was necessary, in cases, for example, that a claim was weak. The MSc students' engaged in *collective but egotistic argumentative dialogue* which means that their aim was first to persuade and convince their peers of their reasoning, and then on building consensus; they focused mostly on contradicting their peer's reasoning, making counterclaims that were left unsupported, and some occurrences of integrating and advancing the peers' reasoning. In contrast, the novices did not manage to engage in a collective argumentative dialogue but rather in *collective monologue* and focused on producing claims without advancing or refuting their peers' reasoning which prohibited the problem solving process.

The results of our study highly support Baker's argument:

> *"a bridge remains to be built between theories of cooperative learning and theories of communicative interaction"* [4, p. 1]

This relationship becomes particularly important when collaboration occurs in problem-solving settings with the aim of learning and knowledge construction; pair activities that do not attend to the communicative interaction and how this is structured, do not indicate effective collaboration, productive dialogue and successful learning outcomes. For instance, while Peer Instruction has been suggested as beneficial to students' learning (e.g., [56, 60]), concerns have been raised regarding the way students' communicate and how all students can be part of the discussion (e.g.,[21, 30, 43]). Prior studies have demonstrated that scaffolding effective communication (e.g., collaborative scripts or examples) in collaborative settings facilitates common understanding and problem solving performance ([52]); thus, understanding what it entails to effectively and productively engage in collaborative problem solving is essential to design such activities. Our findings suggest that highly competent collective reasoners in our field should be able to generate arguments based on different argumentative schemes, support them with reasons and re-evaluate them when challenged; they should be able to deeply consider arguments counter to their own, refute them and question them when necessary, and re-construct them and advance them appropriately.

Seeing reasoning as a form of social practice, manifested in dialogical argumentation, necessitates a turn in educational practices that emphasises and makes explicit the role of collective argumentative reasoning and what it entails; students should be provided with opportunities, both at the classroom level and during peer to peer collaboration, to capitalise on argumentative skills in the context of programming education both as a means to effective problem-solving but also as a means to co-construct domain knowledge, develop higher-order skills and epistemological ways of thinking.

Our future research aims to investigate in depth the role of collective argumentative reasoning in programming education and how it can be embedded in programming learning environments. We are particularly interested in investigating whether and how novices can be trained to employ argumentative schemes and argumentative moves as a means to facilitate knowledge construction, tackle common misconceptions (e.g., [34, 35, 62, 63]) and collaborate more effectively in group problem-solving activities. We envision constructing a pedagogical framework that puts at the centre of programming education argumentative reasoning and to shape, thus, the epistemological discourse that takes place in programming classrooms during both teaching instruction and peer to peer interactions.

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