PROMOTING METACOGNITION IN CLASS. USE OF MODEL ELICITING ACTIVITIES AND REVERSE ENGINEERING IN INITIAL TEACHER TRAINING

PROMUOVERE LA METACOGNIZIONE IN CLASSE. USO DI MODEL ELICITING ACTIVITIES E REVERSE ENGINEERING NELLA FORMAZIONE INIZIALE DEI DOCENTI

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ABSTRACT
The contribution reflects on the need for teacher training to promote metacognitive skills in the classroom. The sample is composed of 110 teachers from the teacher training courses outlined in the DPCM 4/08/2023. We gave them Model-Eliciting Activities whose structural elements had to be identified through reverse engineering. The hypothesis we aim to test is whether collaborative and metacognitive reflection on MEAs could improve teachers' self-regulation and sense of self-efficacy

Il contributo riflette sulla necessità della formazione dei docenti per promuovere competenze metacognitive in classe. Coinvolge 110 docenti dei percorsi abilitanti (DPCM 4/08/2023) a cui sono state proposte delle Model-Eliciting Activities, i cui elementi strutturali dovevano essere identificati attraverso un percorso di reverse engineering, ipotizzando che la riflessione collaborativa e metacognitiva sulle MEA possa migliorare l'autoregolazione dei docenti e il loro senso di autoefficacia.

KEYWORDS
Initial teacher training, Mental Models, Metacognition, Self-Regulation
Formazione docenti, Modelli mentali, Metacognizione, Autoregolazione

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Introduction

The paper aims to reflect on the need for teacher training courses aimed at promoting metacognitive skills within teaching practice, considered pivotal to promote continuous, reflective and autonomous learning, capable of responding effectively and consciously to the complex challenges of a rapidly and constantly evolving world. The research is based on two main theoretical assumptions: The first concerns the crucial role of mental models (Johnson-Laird, 2005; Johnson-Laird & Khemlani, 2014) and the construction of conceptual artifacts (Nowack & Caspersen, 2014) in the learning process (Seel, 2003; 2017; Novak & Cañas, 2008) as will be illustrated in the following paragraphs; the second refers to the hypothesis of a reciprocal influence between metacognition, self-regulation and self-efficacy (Arianto & Hanif, 2024). With this in mind, we involved a group of teachers attending the qualifying courses (DM 04/08/2023), proposing them some Model-Eliciting Activities (MEAs) (Lesh & Zawojewski, 2007). These, focused on the creation of conceptual models or symbolic representations for the resolution of authentic problems, are designed to stimulate collaboration, critical thinking and, above all, to promote self-regulation and metacognitive reflection (Lesh & Harel, 2003; Pane, Syahputra & Mulyono, 2017). Teachers were asked to analyze and decompose MEAs into their structural elements, through reverse engineering (Queloz, 2021), with the aim of activating a collective metacognitive reflection on the modeling process itself. The aim of the research is twofold: on the one hand, it intends to investigate whether the metacognitive and self-regulation strategies implemented by teachers are positively correlated with the sense of perceived self-efficacy in promoting metacognition in the classroom; on the other hand, it explores whether teaching activities based on the construction of models - recognized in the literature as effective tools for metacognitive control and learning regulation - can represent real training strategies to enhance teachers' professional self-efficacy.

1. Mental models, metacognition and self-regulation in learning

Literature highlights the interconnection, in learning processes, between self-regulation, metacognition (Pintrich, 2002; Zimmerman, 2002; Arianto & Hanif, 2024) and mental models (Treur, 2021; 2022). Metacognition, i.e. awareness and control over one's cognitive processes (Flavell, 1979; Veenman, 2006), is a fundamental prerequisite for self-regulation of learning (Schraw, Crippen & Hartley, 2006), which includes the planning, monitoring and evaluation of strategies used to achieve objectives (Zimmerman, 2000; Efklides, 2011). In this framework, mental models - internal cognitive structures that represent concepts, phenomena or systems in a simplified but functional way (Johnson-Laird, 1983; 2005) - take on a central role in the construction of meaning, in the processing of information and in the resolution of problems (Lesh & Harel, 2003) and are therefore considered as the internal representations that individuals use during learning (Gentner & Stevens, 1983; Greca & Moreira, 2000; Seel, 2006; 2017). Metacognition plays a crucial role in regulating their use and adaptation, especially when using multiple models to learn complex concepts (Treur, 2021; 2022; Gentner & Stevens 1983; Greca & Moreira 2000), as it allows students to evaluate the validity and effectiveness of their models, favouring their revision and refinement in response to new information or interpretative failures (Treur, 2022). In this process, external representations do not play a merely illustrative role, but operate as cognitive artifacts (Nowack & Caspersen, 2014; McCrudden & Rapp, 2015) that externalize and support manipulation and reflection on mental models (Clement & Rea-Ramirez, 2008), reinforcing metacognitive self-regulation (Azevedo & Cromley, 2004; Brenner, 2022). What emerges is an integrated framework in which the quality of learning depends on the ability to consciously build, monitor and restructure his or her mental models, also through the strategic use of external tools (Windschitl & Thompson, 2013; Novak & Cañas, 2008).

2. MEAs, Reverse engineering and mental models

The research is based on the assumption that the construction of mental models represents a key process in meaningful learning and in the resolution of complex problems (Treur, 2021; 2022; Giere, 2004; Gentner, 2002; Gentner & Stevens, 2014). Such models can be developed through teaching strategies that stimulate the creation of conceptual relations, the visualization of thought and the explication of one's own reasoning processes (Nowack & Caspersen, 2014; Windschitl & Thompson, 2013; Novak & Cañas, 2008). In this perspective, we have identified two specific strategies - *Model-Eliciting Activities* (MEAs) (Garfield, delMas & Zieffler, 2009; Lesh & Zawojewski, 2007) and *reverse engineering* (Queloz, 2021) - originally developed in STEM contexts, but which lend themselves to being effectively adapted to the educational field (Almeida & Alves Lopes, 2023), as transversal methodologies that overcome disciplinary boundaries. Both aim at the construction of mental models and visual artifacts intended as tools to represent, conceptualize and deal with problematic situations. MEAs require students - or, in our case, teachers - to produce modelled solutions to authentic problems, while reverse engineering promotes the structural and reflective analysis of complex activities, making implicit mechanisms of thought visible and favouring metacognitive and self-regulatory processes. These methodologies, if included in training courses for teachers, can contribute to the development of more conscious, reflective teaching practices oriented towards the promotion of metacognition in class.

2.1. Model Eliciting Activities

Among the methodologies that can be adopted to develop model-based teaching are *Model Eliciting Activities (MEAs)* (Lesh & Zawojewski, 2007; Garfield & delMas & Zieffler, 2009), designed as open-ended questions and complex real problems, with the aim of stimulating the individual to invent and test models.
MEAs are used above all for problem solving (Pertamawati & Retnowati, 2019), because they lead to the creation of a representation that allows the problem to be understood, analyzed and solved through the systematic organization of ideas and exploration of different solutions. MEAs can also help in the promotion of critical thinking because require a thorough search for the main information and concepts of the content; moreover, the construction and evaluation of models and the review based on feedback and results invite students to implement self-regulatory and metacognitive strategies (Lesh & Harel, 2003; Garfield, delMas & Zieffler, 2009), also making thought visible.
MEAs are structured on the basis of six principles (Lesh et al., 2000):

1. *Model construction principle:* Problems must be designed in such a way as to allow the creation of a model that is composed of elements, relationships and operations between elements, as well as schemas and rules that determine these relationships
2. *The reality principle:* Problems must be meaningful and relevant to students, and be based on real or slightly modified data. The solution must be realistic and meaningful to students' daily lives
3. *Self-assessment principle:* Students must be able to self-evaluate or measure the usefulness of their solutions, promoting the selection, refinement and development of models, therefore they must clearly present the goal to be achieved and the criteria on the basis of which to determine when the solution was reached. To reach the latter, students must be able to identify the shortcomings of the current conceptualization,

compare alternatives and select the most promising ones, integrate their strengths and minimize their weaknesses.

4. *Model documentation principle:* Students must be able to reveal and document their thought processes within their solution. The activity should encourage self-reflection, so that students reflect on their thinking (metacognition).
5. *Model Shareability and reusability principle:* The model created to solve the problem must represent a general way of thinking, not a specific solution for a specific context. This also includes the ability to communicate the model clearly and understandably to others.
6. *Effective Prototype principle:* This ensures that the model produced is as simple as possible, but still mathematically meaningful. The model should provide a metaphor for interpreting other problems with the same underlying structure.

These principles contribute to making the activity a modelling process that allows not only a deeper understanding of the contents and the generalization of the knowledge acquired, but also the creation of a visible and concrete representation of the thought and reasoning processes underlying the resolution of the task (Windschitl, 2013; Ritchhart & Perkins, 2008). In this way it can stimulate metacognitive reflection and self-regulated learning, i.e. the ability to consciously and effectively plan, monitor and evaluate one's cognitive and metacognitive strategies in order to achieve learning objectives (Zimmerman, 2000; Pintrich, 2002; Schraw, Crippen & Hartley, 2006).

2.2. Reverse Engineering

Conceptual reverse engineering is a process of retrospective analysis that reconstructs the pragmatic conditions that led to the formation of a concept, a backward process that aims to discover the function or purpose of a conceptual practice or idea, trying to understand what need or practical problem it addresses and why we have come to think of it that way (Almeida & Alves Lopes, 2023; Queloz, 2021). It differs from simple conceptual engineering (Cappelen & Plunkett, 2020) because it does not only try to define concepts through necessary and sufficient conditions but welcomes exceptions and variations, and tries to understand the function of concepts in the context in which they are used. It is not a matter of an *a priori* justification of the elements of the object of analysis - in this case a didactic activity - but rather of an *a posteriori* reconstruction of the needs or practical problems to which it tries to respond. This process of retrospective conceptual analysis makes it possible to bring order to heterogeneous conceptual practices, identifying an underlying functional unit (Thomasson, 2020) and demystifying abstract entities, translating ideas in terms of human needs: reverse engineering therefore represents a sort of pragmatic genealogy that allows us to explain the origin and function of concepts (Queloz, 2021). The main focus is on *why* a conceptual idea or practice is, its usefulness and the role it plays for us.

The choice to integrate *Model Eliciting Activities* with *reverse engineering* is motivated by the fact that the two strategies share a similar conceptual structure. MEAs are based on realistic problems that require the formulation of generalizable solutions and can therefore be seen as a practical form of reverse engineering: students, starting from a concrete problem, build a functional model backwards, revealing their thinking and conceptions in the process. Although not identical, the process of a MEA can be seen in a sense as going backwards from the problem to creating a model that solves it. Students start from a real problem situation and must engineer a model that works for that situation and for similar ones, identifying and reconstructing in detail the reason for something. MEAs are also designed to reveal students' thinking through the artefact they produce: this process is not only shared by conceptual reverse engineering that seeks to make explicit the purpose and logic underlying a concept, but also allows us to understand students' reasoning, thinking mechanisms and knowledge. In this sense it is a sort of "reverse engineering" of the participants' knowledge, and performing an important metacognitive function. Therefore, integrating these two practices can allow a retrospective understanding of the formative needs, learning mechanisms and concepts underlying the didactic activities, acting as a support for a reflective and informed teaching design.

3. The research

The aim of the present research is to investigate a) whether the teacher's metacognitive and self-regulation strategies correlate positively with the self-efficacy related to the promotion of metacognition in the classroom and b) whether teaching activities based on the creation of models - which in the literature are valid tools for metacognitive control and self-regulation of learning - can become training strategies to increase the teacher's self-efficacy. Starting from this dual objective, the following research questions were formulated:

Q1: *What is the relationship between metacognition, self-regulation and teacher self-efficacy with respect to the promotion of metacognition in the classroom?*

Q2: *What role do modeling-based teaching strategies play in the development of metacognition and self-regulation?*
The hypothesis we propose, to answer these questions, is that educational activities based on the construction of mental models positively affect, directly or indirectly, metacognition, self-regulation and self-efficacy with respect to the promotion of metacognition.

3.1. Sample

The sample is made up of 110 teachers enrolled in the qualifying courses outlined in the Minister of Education and Merit's DM 04/08/2023 for different subjects (A022, A048, A027 and A028). Following data cleansing and elimination of outliers, the analysis was conducted on a total of 42 participants.

3.2. Procedure

The research took place in several meetings over a quarter, in which participants completed questionnaires composed of several validated scales, administered before and after the activity. The scales used are that of *Teachers' Self-regulation skills*, composed of the subscales *metacognitive*, *cognitive* and *motivational regulation* (Karlen et al., 2023); the scale of the *Promotion of metacognition* (Karlen et al., 2023); and finally the subscales of *Procedural knowledge* and *Information management strategies* taken from the *Metacognitive Awareness Inventory* by Schraw & Dennison (1994). Along with these, the *Group Self-Regulation* scale (adapted from Chen, 2020) and three open-ended questions on the *Utility Beliefs regarding Mental Representation Strategies* (with respect to *understanding* and *solving* the problem and *communication* with the peers) were also administered.
During the meetings, in addition to training activities related to metacognition and teaching strategies to promote it, the teachers were involved in a brainstorming on the use of visual representations and artifacts in teaching and in two problem solving activities, one based on the creation of concept maps and visual algorithms and one based on the creation of models. Here we focus on the results related to the latter, as the preliminary results of the previous meetings (Battaglia, Melchiori, 2025) have made it possible to identify some critical issues that have been addressed in the development of this further phase.
The teachers, divided into homogeneous groups by subject, were asked to carry out an activity that combined model eliciting activities and reverse engineering. They were therefore given a MEA, formulated starting from the principles proposed by Lesh and colleagues (2000), together with possible solutions of the activity; Starting

from these solutions, through a process of reverse engineering, teachers had to identify the pedagogical principles and structural characteristics of the activity, identify the educational needs of the students to whom they would propose this exercise and develop a visual model that could provide a structure replicable in other formative contexts. In this case, the reverse engineering activity became a MEA whose objective was the creation of a model relating to the MEA itself; in this way, an attempt was made to create an activity with a strong metacognitive and reflective connotation on the teaching strategies implemented.
Before (T1) and after (T2) the activity, the teachers filled in a questionnaire consisting of the scales mentioned above.

4. Results and Discussion

Model Fit

Model	**R**	**R²**
1	0.634	0.401

Coefficients - SRL_Skills_T2

Predictor	**Estimate**	**SE**	**t**	**p**
Intercettare	25.8973	10.236	2.530	0.016
MAI_T1	0.8714	0.181	4.826	< .001
Age	-0.0304	0.147	-0.206	0.838
Gender	-0.3789	2.441	-0.155	0.878
Course	2.2081	2.574	0.858	0.397

Table 1. Linear Regression – *Self-Regulation Skills*

Model Fit

Modello	R	R^2
1	0.697	0.485

Coefficienti del Modello - MAI_T2

Predittore	Stima	SE	t	p
Intercettare	17.2325	6.8906	2.5009	0.018
Age	-0.0619	0.0988	-0.6270	0.535
Gender	1.3247	1.6392	0.8081	0.425
Course	-0.2481	1.7548	-0.1414	0.888
Metacognitive_Reg_T1	0.4050	0.4660	0.8690	0.391
Cognitive_Reg_T1	0.8590	0.5168	1.6620	0.106
Motiv_Reg_T1	0.0154	0.4462	0.0344	0.973
Promotion_T1	0.1370	0.1990	0.6883	0.496

Table 2. Linear Regression – *Metacognition*

Effect	Estimate (B)	SE (Bootstrap)	z-value	p-value	95% CI Lower	95% CI Upper
Path a (Metacognition_T1 ➔ Self_Regulation_T2)	0.551	0.118	4.665	< .001	0.318	0.766
Path b (Self_Regulation_T2 ➔ Promotion_T2)	0.643	0.166	3.883	< .001	0.288	0.928
Direct effect c′ (Metacognition_T1 ➔ Promotion_T2)	-0.266	0.128	-2.073	.038	-0.501	0.000
Control effect (Promotion_T1 ➔ Promotion_T2)	0.383	0.092	4.168	< .001	0.176	0.557
Indirect effect (a × b)	0.355	0.119	2.986	.003	0.126	0.585
Total effect (Direct + Indirect)	0.088	0.128	0.689	.491	-0.160	0.341

Table 3. Mediation model – *Metacognition, Self-Regulation & Promotion of metacognition*

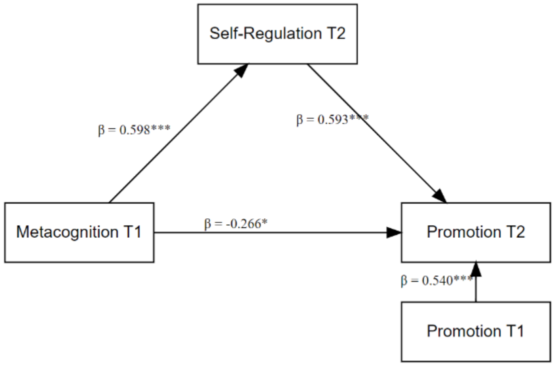

Figure 1. Mediation model – *Metacognition, Self-Regulation & Promotion of metacognition*

Effect	**Estimate (B)**	**SE (Bootstrap)**	**z-value**	**p-value**	**95% CI Lower**	**95% CI Upper**
Path a (Utility_T1 ➔ Self_Regulation_T2)	β=0.427	SE=0.101	z=4.219	p=.001	0.229	0.626
Path b (Group_Self_Regulation_T2 ➔ Promotion_T2)	β=0.400	SE=0.122	z=3.268	p=.001	0.160	0.640
Direct effect c' (Utility_T1 ➔ Promotion_T2)	β=0.272	SE=0.124	z=2.194	p=.028	0.029	0.515
Control effect (Promotion_T1 ➔ Promotion_T2)	β=0.359	SE=0.119	z=3.019	p=.003	0.126	0.592
Indirect effect (a × b)	β=0.171	SE=0.071	z=2.419	p=.016	0.032	0.309
Total effect (Direct + Indirect)	β=0.443	SE=0.107	z=4.149	p=0.000	0.234	0.652

Table 4. Mediation model – *Perceived utility of representation, Group Self-Regulation, & Promotion of metacognition*

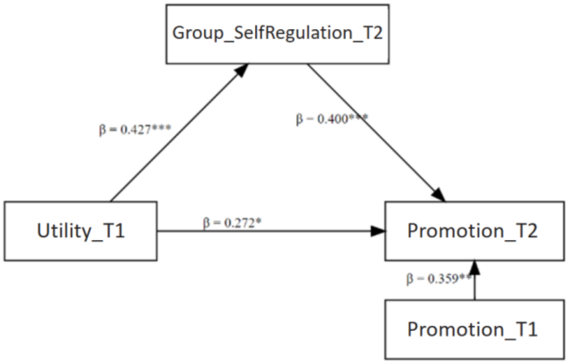

Figure 2. Mediation model – *Perceived utility of representation, Group Self-Regulation, & Promotion of metacognition*

The results of T1 and T2 were analysed with the aim of both verifying the validity and reliability of the tests used, and of testing the research hypothesis, i.e. whether there are significant differences in the values of self-regulation, metacognition and self-efficacy (with respect to the promotion of metacognition in the classroom), and also to verify the interaction between these dimensions and the training activities carried out. The internal consistency of the scales and subscales used was evaluated by means of the Cronbach Alpha coefficient. The values obtained correspond to a $\alpha>.80$ or $\alpha>.90$ for all scales, thus being higher than the cut-offs commonly accepted in the literature ($\alpha>.80$), indicating a high internal consistency of the items for each measured construct. This result confirms the metric soundness of the tools adopted for the detection of the latent variables considered, including self-regulation, metacognition and promotion of metacognition. As regards test-retest reliability, Pearson or Spearman correlation coefficients (depending on the normality of the scales) between measurements taken at time 1 (T1) and time 2 (T2) were calculated. The results show moderate correlations, with coefficients ranging from .50 to .70. These values suggest some variability in scores over time and a potential limit in terms of temporal reliability, but they are still moderate values and consistent with an intervention that required measurements in close time (two weeks). After analysing the consistency and reliability of the scales used, we verified whether there were statistically significant differences between the two administrations by means of a t-test for paired samples. The analyses highlighted statistically significant differences in some specific dimensions, including *motivational regulation* ($p<.001$) (the only subscale of learning self-regulation to show significant differences), *metacognition* ($p=0.002$) – both with regard to the subscale of *procedural knowledge* (p=0.38) and *information management strategies* (p<.001) – and the *promotion of metacognition* (p=0.017), results that highlight a possible positive effect of the activities carried out on the metacognitive and motivational processes of teachers, as well as their self-efficacy. We then proceeded with the linear regression analysis to identify which socio-demographic variables (gender, age, educational background) and psychological variables (metacognition, self-regulation, promotion of metacognition) could explain the variance of the dependent variables analysed. In the first model (Tab.1), which includes gender, age, educational background, and metacognition as predictors, the coefficient of determination (R^2) indicates that the model explains about 40% of the variance in the self-regulation, and metacognition emerges as a statistically significant predictor ($p<.05$), confirming its central role in self-regulated processes. In the second model (Tab. 2) the dependent variable is metacognition and gender, age and course, together with the dimensions of self-regulation and the promotion of metacognition, were included among the predictors. The variance explained is 48% ($R^2=.485$) but no predictor is statistically significant, suggesting the possible presence of multicollinearity or complex relationships between the dimensions considered. Finally, with regard to the promotion of metacognition, no model has been able to identify predictors that sufficiently explain its variance. In order to consider both the improvement in the values of self-regulation, metacognition and self-efficacy with respect to the promotion of metacognition as a result of the visualisation-based formative interventions, and the link between these dimensions, a further analysis of the interactions between them and the perceived usefulness of the strategies adopted during the activities was carried out, through two mediation models tested using bootstrapping with 5000 resamples. In the first mediation model (Tab.3; Fig.1), metacognition at Time 1 predicted Promotion of Metacognition at Time 2, both directly ($\beta=-0.266$, SE=0.125, z=-2.131, p=.033, 95% CI [-0.511, -0.021]) and indirectly through Self-Regulation at Time 2 ($\beta=0.355$, SE=0.102, z=3.460, p=.001, 95% CI [0.154, 0.555]), which also significantly predicted Promotion of Metacognition T2 ($\beta=0.593$, SE=0.146, z=4.058, p<.001, 95% CI [0.306, 0.879]), although the total effect was not statistically significant ($\beta=0.088$, SE=0.128, z=0.688, p=.491, 95% CI [-0.163, 0.340]).

Additionally, Promotion of Metacognition T1 positively predicted Promotion of Metacognition T2 ($\beta=0.540$, SE=0.120, z=4.516, p<.001, 95% CI [0.306, 0.775]).

In this model it was demonstrated that Self-Regulation at Time 2 significantly mediated the relationship between Metacognition at Time 1 and the Promotion of Metacognition at Time 2. This result aligns with extensive literature emphasizing that early metacognitive monitoring and control skills serve as foundational mechanisms for the later development of broader self-regulatory capacities (Veenman, Van Hout-Wolters, & Afflerbach, 2006; Efklides, 2011). The positive indirect effect observed is consistent with theoretical models of self-regulated learning (Zimmerman, 2002), which postulate that metacognitive knowledge and skills act as precursors enabling individuals to intentionally plan, monitor, and adapt their learning processes and instructional strategies over time. Importantly, the persistence of a significant negative direct effect, once the mediating pathway was accounted for, may suggest the presence of a suppression effect (MacKinnon, Krull, & Lockwood, 2000), indicating that the influence of metacognitive abilities on promotional practices is predominantly realized through the enhancement of self-regulatory behaviors, rather than direct, unmediated application. The second mediation model (Tab.4; Fig.2) extended these findings by focusing on the role of Utility Beliefs regarding Mental Representation Strategies at Time 1, a motivational-cognitive construct, and its influence on Promotion of Metacognition at Time 2 through Group Self-Regulation at Time 2. In this model, Utility of Mental Representations at Time 1 predicted Promotion of Metacognition at Time 2, both directly ($\beta=0.272$, SE=0.124, z=2.194, p=.028, 95% CI [0.029, 0.515]) and indirectly through Group Self-Regulation at Time 2 ($\beta=0.171$, SE=0.071, z=2.419, p=.016, 95% CI [0.032, 0.309]), which significantly predicted Promotion of Metacognition T2 ($\beta=0.400$, SE=0.122, z=3.268, p=.001, 95% CI [0.160, 0.640]). Additionally, the model controlled for Promotion of Metacognition at T1, which had a significant positive effect on Promotion of Metacognition at T2, ($\beta=0.359$, SE=0.119, z=3.019, p=.003, 95% CI [0.126, 0.592]). Model fit indices showed an acceptable fit to the data ($\chi^2(1)=5.339$, p=.021, CFI=0.907, SRMR=0.091). The results of this model indicated that teachers who perceived greater utility in cognitive representation strategies were more likely to activate and sustain self-regulatory processes within collaborative contexts, which subsequently translated into greater promotion of metacognitive practices. This pattern resonates with the conceptualization of socially shared regulation of learning (*SSRL*) (Hadwin, Järvelä & Miller, 2011), emphasizing that self-regulation does not solely occur at an individual level but can be co-constructed within group activities, thus enhancing individual cognitive and motivational outcomes. Moreover, it supports frameworks positing that motivational appraisals, such as perceived strategy utility, are critical drivers not only of individual engagement but also of the adoption of metacognitively informed instructional practices (Panadero, 2017; Greene, 2018). Taken together, these findings substantiate the view that self-regulation functions as a central mediating mechanism through which both cognitive beliefs (e.g., metacognitive awareness) and motivational beliefs (e.g., utility perceptions) impact the enactment of pedagogical practices aimed at fostering metacognitive development in learners. This aligns with multidimensional models of teacher professional development (Vermunt & Donche, 2017), which emphasize that the integration of cognitive, motivational, and regulatory components is essential for the evolution of effective, reflective educational practices. In this light, self-regulation emerges not merely as a parallel or ancillary process but rather as a dynamic mediator, serving to translate internal cognitive-motivational dispositions into observable instructional behaviours that support metacognitive growth in students, highlighting a chain mechanism that enhances the interaction between cognitive, metacognitive and self-regulatory processes.

Conclusions

The research illustrated hypothesised that teaching activities based on the creation of mental models may positively influence the teacher's self-efficacy with respect to the promotion of metacognition, starting from a possible interaction between metacognition, self-regulation and self-efficacy. A previous phase, based on the creation of concept maps and visual algorithms, had shown significant improvements in teachers' perceptions of their abilities to metacognitive regulation and promote metacognition in the classroom (Battaglia & Melchiori, 2025), partly supporting the research hypothesis, but at the same time highlighted some critical issues, mainly related to the tight time frame and the lack of involvement of the teachers who had perceived the activity proposed as distant from one's own discipline and profession. The lack of reflective and metacognitive moments to discuss the practical usefulness of the training activity was also an important limitation. In this second phase we tried to reduce, as far as possible, these limitations: the proposed MEAs presented specific problems related to the teacher's subject, and this allowed them to be more involved, as emerged from the improvement in the dimension of motivational regulation. In addition, we tried, as far as possible, to leave more time for the performance of the task which was set up, thanks to the reverse engineering technique, to provide moments of reflection and translation into teaching practice of the activity carried out. Finally, compared to the first phase of the research, the strategies used were not simply based on the visualization of mental models but invited teachers to build from scratch and to continuously refine them, and this made it possible to investigate not only the possible change in the levels of self-regulation, self-efficacy and metacognition but also the role that the strategies used had in this change. Therefore, despite the limitations of the research that could not be completely neutralized, the results illustrated here still suggest relevant information on the reciprocal interaction between mental models and certain aspects of learning, such as self-regulation and metacognition, and on the possibility of promoting teachers' self-efficacy through targeted training activities.

Author contributions

The research was developed and carried on by both authors. Maria Vittoria Battaglia wrote the Introduction; §1; §2. Francesco Maria Melchiori wrote §3. Together they wrote §4 and conclusion.

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