A Transactive Memory System Perspective in Software Engineering Education

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Abstract—*Contribution:* **Results and conclusions on the use of transactive memory system (TMS) in software engineering (SE) education in student project teams that consist of undergraduate and postgraduate students are documented. This can be valuable for the adoption of this learning approach and team formation by other universities and institutes.**

Background: **Preparing students for the SE industry requires bringing them in close collaboration to real-world tasks. This is usually performed via students carrying out software projects, working in teams. In such environments, the knowledge sharing and the interactions within the team are worth investigating, as they can affect the outcome of the student collaboration and can provide insight on how the collaboration is valued by the team members.**

Research Questions: **1) What is the effect of TMS on students in SE education? 2) Do parameters, such as gender, affect TMS development? 3) Does the inclusion of a project manager with more expertise affect TMS?**

Methodology: **Students were divided into teams working on SE projects. Teams consist of both undergraduate and postgraduate students. Data from students on TMS for consecutive academic years were gathered.**

Findings: **TMS is present in student teams and some of its scale items are affected by parameters, such as the team composition and the project type. TMS also affects performance.**

Index Terms—**Project management, software engineering (SE) education, transactive memory system (TMS).**

I. Introduction

Software engineering (SE) education in higher institutions is preparing students for the real industry world. The main aim is to make them responsible software engineers, able to carry out different tasks. Applied learning, as a measure to prepare for career success, has been identified in earlier studies [1]. Decreasing the gap between the education and the industrial practice is not easy [2]. In order to perform this process effectively, bringing students close to industrial settings working with external organizations is required, whereas experience from working in a team is also an important asset for students, as a way to simulate working in SE project teams. Project management is also very important in software system development in practice and in SE education, as it can have a significant effect on the success or the failure of a software project identified mainly in poor project planning and direction [3]. Collaboration is vital in this process and knowledge sharing is an important part of a successful team. The importance of project management education is discussed in an earlier work, which, starting from the use of SE body of knowledge (SWEBOK), introduces a transition that enriches the SE curricula with knowledge from the software project management extracted from the software extension to the guide of the project management body of knowledge (PMBOK) [4].

Soft skills also play an important role in the SE practice [5]. Soft skills cover a set of competences outside technical knowledge and are vital in different environments (e.g., visual communication and writing skills), whereas teamwork and communication also fall within soft skills. The importance of such abilities has also been identified by the organization for economic co-operation and development (OECD) as part of the EUR-ACE framework standards for the accreditation of engineering programs [6].

In this context, the transactive memory system (TMS) can be a useful asset [7]. TMS represents the collective awareness of the team's *knowledge specialization*, *task credibility*, and *task coordination*; three aspects that are considered very important for a successful team in SE projects, as they concern the group mind and may affect the team efficiency. The purpose of this article is to present the results of an alternative approach to education for SE and SE project management, by placing postgraduate (i.e., master) and undergraduate (i.e., bachelor) students together in the same development teams. Through the students' interaction and collaboration, the authors aim to investigate the development of TMS and its parameters as evidence of knowledge sharing, development of trust, and management of coordination within the student engineering teams as applied at the University of Cyprus.

Preliminary results of the development of TMS in these settings were presented in a previous work of the authors [8]. In the current work, this previous work is continued by describing in detail the process followed for the development of TMS and by presenting the results of the adoption in consecutive years, including thus a larger number of students, and a deeper analysis that helps in drawing useful conclusions. This article investigates mainly the student experience. The main contributions of this article include: 1) the presentation of the combination of undergraduate and postgraduate students in student project teams with relevant learning advantages; 2) the development of TMS in SE education; and 3) documenting

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TABLE I
TMS DIMENSIONS AND RESPECTIVE SCALE ITEMS

Specialization
1. "Each team member has specialized knowledge of some aspect of our project."
2. "I have knowledge about an aspect of the project that no other team member has."
3. "Different team members are responsible for expertise in different areas."
4. "The specialized knowledge of several different team members was needed to complete the project deliverable."
5. "I know which team members have expertise in specific areas."
Credibility
1. "I was comfortable accepting procedural suggestions from other team members."
2. "I trusted that other members' knowledge about the project was credible."
3. "I was confident relying on the information other team members brought to the discussion."
4. "When other members gave information, I wanted to double check it for myself." (*reversed*)
5. "I did not have much faith in other members' 'expertise'." (*reversed*)
Coordination
1. "Our team worked together in a well coordinated fashion."
2. "Our team had very few misunderstandings about what to do."
3. "We accomplish the task smoothly and efficiently."
4. "Our team needed to backtrack and start over a lot." (*reversed*))
5. "There was much confusion about how we would accomplish the task." (*reversed*)

the main results and lessons learned that can be useful for future adoptions.

II. Background and Related work

A. Transactive Memory System

Transactive memory is concerned with "the prediction of group and individual behavior through an understanding of the manner in which group processes and structures information" [7]. The main element in the ability of a TMS to function is for the divergent information existing in the mind of each member to be known by the other team members. Under this perspective, it is assumed that the memory of member *A* can act as an extension of the memory of member *B*. If the member *B* is aware of what *A* knows, then she should be able to gain access to the information possessed by *A*, when this is required. Teams can profit from the existence of a TMS, since members are aware of the knowledge held by the other team members. Since the TMS is a multidisciplinary theory, a widely accepted method for its measurement has not been established yet [9]. A widely used and validated field measure is the one introduced by Lewis, where TMS is decomposed into its three parameters: 1) specialization; 2) credibility; and 3) coordination. The TMS scale items that were used in this article adopting the field measure of Lewis are shown in Table I [10]. To measure each scale item in the three TMS dimensions, a five items Likert scale is used for each of the 15 items: strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree.

B. Related Approaches

Various approaches to SE education exist. Reflexive weekly monitoring was used for student team projects in order to help students understand their own performance and the project status [11]. Rusu *et al.* [12] paired teams of students across two universities, who collaborated in the framework of real-word projects. This approach also mixed postgraduates with undergraduates students of the upper level, but focused on drawing main conclusions from the course structure and the student perspective without investigating the combination of students with different level of expertise in the teams, that is one key point being addressed in the current work.

Different aspects that affect students working in teams in engineering projects were also studied previously [13]. An interesting outcome relevant to the current work was that most students (77%) indicated that they learned and gained valuable skills via the interaction with other team members. Some previous works have examined the effect of SE projects on students such as for the case of self-efficacy [14]. The gender aspect in SE teams is investigated in a case study that compared the results of teams of mixed gender and male teams in student software projects [15]. One of the main outcomes was that these mixed gender teams can bring an improvement in the results of SE teams. Kapitsaki and Kleanthous [16] investigated other features of team collaboration in student teams.

Team dynamics in terms of student participation were studied in a work that used large teams that would collaborate for a short period of time in order to complete SE tasks in the framework of mini projects [17]. Peer reviews with students were used to examine their view on the participation of individuals, examining for this respect the effect of team composition and the behavior of other team members. In contrast to the above, in the current work, emphasis is put on the team level and team interactions in the framework of TMS.

The TMS was considered an important knowledge-generating factor for group learning, such as in the context of cross-functional groups in automotive companies [18], whereas it can also be considered a good predictor of group performance in the classroom [19]. A literature survey that gathers various works on the connection between communication and TMS is available in [20].

The use of TMS has been studied in the framework of the SE research also in the past. The importance of expertise coordination based on an analysis of 69 software development teams is addressed in a previous work, concluding that expertise coordination is highly linked with team performance [21]. Ralph *et al.* [22] argued that SE projects have a lot to benefit from understanding and identifying social aspects in the processes of software development projects. Seven social theories have been studied in long-term projects in an attempt to illustrate the necessity for understanding, among other aspects, the development of TMS in SE teams. The authors concluded that TMS in the team can be rather helpful, especially in understanding the expertise and skills available in the team, whereas it is important in successful software development project management.

TMS in information system development projects has also been studied [23]. Data from 236 information system personnel were collected and the main conclusion drawn was that having a mature TMS can have a direct positive effect on the performance, but can also affect it indirectly via the improvement of the communication and the coordination process. Another work investigated knowledge sharing in open-source software teams and information systems development teams [24]. It has concluded that parameters related to TMS can have a positive influence on the quality of the communication of information within the team, on knowledge sharing in the team, on the way the team coordinates tasks and also on the overall team performance. Approaches other than TMS for knowledge sharing among teams can be found in a previous survey [25].

Following these results and works that investigated TMS as a group process in several teams [26], [27], this article is an attempt to investigate the parameters associated to TMS, namely, specialization, coordination, and credibility in the educational settings of SE classes. In relation to previous works, the authors are bringing together students of different expertise that are asked to work together having different roles and are presenting the effect of TMS in this different setting concerning the SE education. Data from different years (four consecutive years) have been gathered that allows to address the issues of the TMS development from different perspectives, i.e., from the view of undergraduate and of postgraduate students, offering thus a more holistic analysis.

III. Approach of Courses

The Department of Computer Science of University of Cyprus is offering courses with a team project in the third year of studies in the framework of *SE* and *Professional Practice in SE* courses (5th and 6th semester, respectively). The first course is compulsory, whereas the second is an elective course. The Department offers also a postgraduate program on Computer Science with various elective courses including *Advanced Topics in SE*. The undergraduate students that undertake the *SE* course work in teams collaborating with an industrial customer, in order to carry out a software development project in phases. The project covers specific client needs. In this framework, the students develop the ability to collect software requirements, analyze modules for software development, design software systems, and implement functional software prototypes. The content of the postgraduate course is aimed at demonstrating an overview of concepts on managing information and communications technology (ICT) projects within an organizational context, discussing the importance of working in teams and the role of each member within a project, and analyzing the importance of proper project management. Both courses use project-based learning as their instructional approach.

Different projects are undertaken by the student teams. The software project can be any kind of application (e.g., customer management system, electronic store, real-estate application, and application for student welfare service). The development process is divided into two main cycles with the first cycle completed in the first course (5th semester) and the second in the second course (6th semester). A project manager is assigned to each team of bachelor students. Most students complete only the first cycle where they implement a system prototype, whereas some students undertake also the second course, where they proceed with the full system implementation and testing. The work presented in this article concerns the experience of the students in the first development cycle.

The postgraduate students' project follows the concept of project management and thus, the students act as project managers for one of the teams formed at the undergraduate course. Although the project manager is not directly from the industry, the postgraduate students are closer to this role. Many postgraduate students are employed in the local software industry and attend the master program on a part-time basis, having thus more practical experience. As part of their role, the postgraduate students are responsible for: 1) organizing meetings; 2) supervising the procedure followed by the team; and 3) completing project management documentation following specific templates, including project management plan, cost management plan, work breakdown structure, risk management, and quality management.

Project teams of four to six bachelor students are formed during the two first weeks of the semester (of 13 weeks in total). Students choose their team members and modifications are performed by the instructor if necessary (e.g., small teams consisted of only two members are merged, a student without a team is assigned to an existing team). A postgraduate student who will act as project manager (or two postgraduate students in some cases, where there is no match between the number of postgraduate students and the number of teams of bachelor students) is assigned to each team (or two teams for the same reason indicated above) taking into consideration the nature of the project of each team.

Some teams are finding a project on their own, whereas others may choose from a set of predefined projects created from requests from the industry, coming from the industrial contacts of the University. In order to make an appropriate assignment or approve/reject the project a team has suggested, the skills of the team members are considered, so that a balance exists in all teams. This process is also followed when assigning project managers or when assigning students with no team to existing teams. Projects are approved by the instructors and they are of similar complexity in terms of implementation, as well as of deliverables, whereas the size of the team is also considered when approving/rejecting projects, to ensure fair grading. All undergraduate students possess the same basic technical knowledge, as they only attend compulsory courses in their program of studies till the semester they attend the SE course. Female students are generally less than male. In case a student needs to be assigned to a team, it is preferable that the assignment results in a mixed gender team, although this is not always feasible.

IV. Methodological Approach and Sample

In this article, the development of TMS on the SE student teams is being studied taking also into consideration the different roles of the members and the characteristics of the teams. In addition, demographic information for the participants has been collected, as well as the final grade on the project they undertook within the SE courses. The study was conducted for three consecutive years (second half of 2016 to second half of 2018), although the data of the last year contain only input from the undergraduate students. A limited number of data from undergraduate students that attended the SE course in

2015 was also collected; therefore, the data span four consecutive academic years. In 2015 and in 2018, no project manager was assigned to the teams, as the postgraduate course was not offered in the respective semesters.

Using the set-up discussed, the students worked in teams and they were asked to answer the TMS scale at the end of the semester. Students were asked to use a link to fill the questionnaire and this was not mandatory. Students were informed of the purpose of the study and by proceeding with answering the TMS scale, they agreed to the consent form.

Data from 175 students were collected: 59 female (34.5%) and 90 male students (52.6%), whereas the remaining (12.9%) chose not to disclose this information and it was not possible to infer it using the data from the project teams. One hundred forty-nine students are undergraduates and 22 postgraduates. In total, members from 42 teams replied to the survey. The analysis of the results was conducted following the work in [10]. Comparative analysis was performed to compare the development of TMS between the teams and the level of study, whereas comparisons were performed to study the effect of the use of the project manager. Generic analysis was also performed to gain an overview of the TMS development within groups considering all years.

Based on the above, the following research questions were used to drive the analysis: RQ1: What is the effect of TMS on undergraduate and postgraduate students in SE education? RQ2: Do parameters, such as gender and project type, affect the TMS development? RQ3: Does the inclusion of an individual with more expertise in the team, acting as project manager, affect TMS?

TABLE II
MEAN VALUES FOR DIMENSIONS PER TEAM

Team	Project type	Specialization	Credibility	Coordination	TMS sum
2015-1	IoT	4.500	3.100	4.200	11.800
2015-6	web	4.300	3.600	3.800	11.700
2016-1	game	3.514	4.200	4.571	12.286
2016-2	web	3.457	4.200	4.229	11.886
2016-3	mobile	3.500	4.000	3.100	10.600
2016-4	web	3.700	4.100	4.150	11.950
2016-5	game	3.667	3.000	4.400	11.067
2016-6	game	4.200	4.543	4.600	13.343
2016-7	web	3.400	3.400	4.100	10.900
2016-8	web	3.125	3.975	3.825	10.925
2016-9	web	3.100	4.400	3.950	11.450
2016-10	web	3.000	3.400	3.400	9.800
2017-1	mobile	3.167	3.900	4.000	11.067
2017-2	web	3.680	4.000	4.280	11.960
2017-3	mobile	2.920	4.200	4.760	11.880
2017-4	web	3.850	3.650	3.600	11.100
2017-5	web	3.867	4.033	4.067	11.967
2017-6	AI	3.633	3.967	3.867	11.467
2017-7	web	3.750	4.250	4.150	12.150
2017-8	web	4.100	4.000	4.333	12.433
2017-9	web	3.800	3.467	4.167	11.433
2017-10	web	3.867	4.000	4.200	12.067
2017-11	web	4.133	4.167	4.433	12.733
2017-12	AI	4.114	3.971	4.057	12.143
2017-13	web	3.550	3.900	4.350	11.800
2017-14	mobile	4.500	4.100	4.950	13.550
2017-15	web	3.800	3.960	4.120	11.880
2018-2	mobile	3.520	3.720	4.400	11.640
2018-3	web	4.000	3.667	4.200	11.867
2018-4	web	4.133	3.400	3.267	10.800
2018-5	IoT	2.720	4.200	3.720	10.640
2018-7	web	3.000	3.100	3.400	9.500
2018-8	desktop	3.560	3.440	3.520	10.520
2018-9	desktop	3.333	3.867	3.867	11.067
2018-10	web	3.300	3.200	3.500	10.000
2018-11	desktop	3.333	2.200	3.067	8.600

V. ANALYSIS AND RESULTS

A. RQ1. Overall TMS Development

The overall TMS for all teams, over the years of the study, was encouraging ($M = 3.862$ and SD $= 0.507$) providing initial evidence of members developing a TMS and understanding the overall complementary knowledge among team members. In all results, the respective scale items of credibility and coordination have been reversed (Table I). Individual dimensions of TMS were also examined: specialization ($M = 3.637$ and SD $= 0.799$), credibility ($M = 3.870$ and SD $= 0.684$), and coordination ($M = 4.078$ and SD $= 0.672$). The mean TMS and the mean values for all dimensions per team are presented in Table II, including cases with answers from at least two members (data for six teams are not presented for this reason, but are used in the subsequent analysis). The application technological area for each team is also shown as project type (IoT corresponds to Internet of Things and AI to Artificial Intelligence). Overall, higher values were observed in item 1 of credibility ($M = 4.43$ and SD $= 0.719$) and item 1 of coordination ($M = 4.43$ and SD $= 0.939$), whereas the lowest values appear for item 4 of credibility ($M = 2.69$ and SD $= 1.224$) and item 2 of specialization ($M = 3.09$ and SD $= 1.371$). Higher *SD* appears in the last two cases and also in item 5 of credibility (SD $= 1.293$), indicating larger differences in how students perceive these items in relation to the other items.

Comparing the results based on the level of studies using the independent samples t-test, there is no significant statistical difference on the overall TMS development and its dimensions between participants in undergraduate and graduate level ($p = 0.868$ for TMS dimensions' mean), although there is a statistical significance in coordination ($p = 0.046$) with postgraduates indicating a higher level of coordination ($M = 4.039$ and SD $= 0.689$ for undergraduates, and $M = 4.346$ and SD $= 0.479$ for postgraduates), which is expected but is also an indicator that the understanding of the team in this dimension differs from the view of undergraduates (i.e., view of the project manager versus the view of the team members with development activities). By examining, each item in more detail, it can be seen that there is a statistical significance in how comfortable students are accepting procedural suggestions from other members (item 1 of credibility: $p = 0.038$). The postgraduate students were more reluctant in accepting suggestions ($M = 4.48$ and SD $= 0.703$ for undergraduates, and $M = 4.14$ and SD $= 0.774$ for postgraduates.) This difference is also observed for some items of coordination. Undergraduates demonstrated a tendency to start over more than postgraduates (item 4 of coordination: $p = 0.004$, $M = 4.15$, and SD $= 1.125$ for undergraduates, and $M = 4.86$

and SD = 0.468 for postgraduates), whereas they were more confused about the desired outcome (item 5 of coordination: $p = 0.044$, $M = 3.91$, and SD = 1.102 for undergraduates, and $M = 4.41$ and SD = 0.796 for postgraduates).

B. RQ2. Exploratory Analysis

Further a statistical analysis was run in order to investigate whether a relationship exists between the TMS development and other parameters, e.g., gender or project type. Out of the 43 teams examined, eight consist only of male students, two only of female students, and the remaining are mixed gender teams. Using the independent samples t-test, there is no difference in TMS and its items in relevance to gender, when considering only participants that have indicated their gender (149 students). However, female students were slightly more comfortable accepting the knowledge of other team members (item 2 of credibility: $M = 4.39$ and SD = 0.743 for female, and $M = 4.14$ and SD = 1.001 for male), and feel that their team worked together slightly better (item 1 of coordination: $M = 4.47$ and SD = 0.858 for female, and $M = 4.21$ and SD = 1.044 for male). Female students have also slightly more faith in other members' expertise than male (item 5 of credibility: $M = 3.95$ and SD = 1.378 for female, and $M = 3.70$ and SD = 1.151 for male) but the higher *SD* renders this difference less significant.

Participants were asked whether they have previously worked together with members of their team. 24% had not, but the remaining 76% had. Executing a t-test analysis revealed that students with prior collaboration had to start over more than students that had not worked together (item 4 of coordination: $M = 4.15$ and SD = 1.149 for students that had worked together in the past, $M = 4.56$ and SD = 0.808 for students that had not). This is an unexpected outcome, as students with prior collaboration are not expected to mention that they needed to backtrack and start over a lot during the project development. However, if this is seen from a different perspective, it may be explained by the fact that students who had worked together in the past were more conscious about required changes within their teams and revealed this in their answers. This is the only item, where a statistical significance exists ($p = 0.033$). By examining this aspect further, it is observed that this difference is attributed mainly to the view of postgraduates, as no statistical difference is detected in this part of coordination, when only undergraduates are considered in the analysis ($p = 0.516$). It is plausible that students with more experience are more conscious about when they had to repeat a work that may have not been performed as desired.

The effect of the project type on the TMS development was examined using the one way ANOVA. Although it would have expected that the type does not affect TMS, statistically significant differences were observed in the dimensions of credibility ($F = 3.353$ and $p = 0.011$) and coordination ($F = 5.518$, and $p = 0.000$), and this difference is also present in the TMS mean ($F = 4.344$ and $p = 0.002$). When considering the scale items, differences can be found in the degree the students found others' knowledge credible (item 2 of credibility: $F = 3.934$ and $p = 0.004$), if they would rely on the

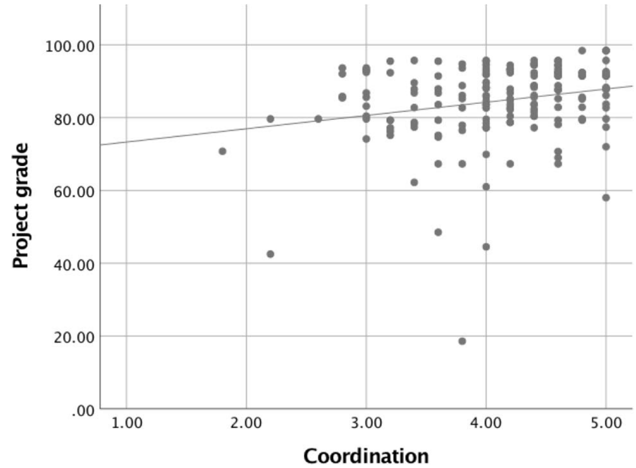

Fig. 1. Correlation between coordination and student project grade.

information others brought (item 3 of credibility: $F = 3.448$ and $p = 0.010$), if the team worked in a well coordinated fashion (item 1 of coordination: $F = 6.498$ and $p = 0.000$), if the tasks were accomplished smoothly and efficiently (item 3 of coordination: $F = 2.994$ and $p = 0.020$) and if the team had to start over a lot (item 4 of coordination: $F = 2.800$ and $p = 0.028$). Regarding credibility, teams with an AI or IoT project were trusting more information from other team members. Since students were less acquainted with these technologies than desktop, Web, and mobile, they might be more positive about trusting other members of their team. For coordination, students with a game project had to start over more. This is also the case for coordination, where students in game projects were less positive about the way the team worked together and was able to accomplish tasks.

The effect of TMS on the project grade obtained by each student was also investigated. For the undergraduates, the grading considers all documentation created by the team, the prototype implementation of the software project, and the collaboration management within the team (e.g., appropriate entries in the KanbanFlow for the project activities scheduling and assignments to team members, communication with the client, and source code version management). Peer assessment was also employed for grading purposes. For the postgraduates, the grading was based on the project management deliverables. Therefore, project grade may vary among the members of the same team. Overall, the project grades students received ranged from 18.58% to 98.4% ($M = 84.518\%$ and SD = 10.847%). Within the teams, the maximum difference in grades between the team members of the same team was 43.1%. A weak positive correlation exists between coordination and the project grade ($r = 0.226$ and $p = 0.003$). Students with higher project grades score higher in coordination, as depicted in Fig. 1. Since two out of the five items of coordination refer to whether there were misunderstandings in the team and how well the team worked together, one explanation for this result can be that students whose team worked more efficiently showed a larger degree of involvement and contributed more to the project, obtaining thus a higher grade. In order verify that prior collaboration of students did not

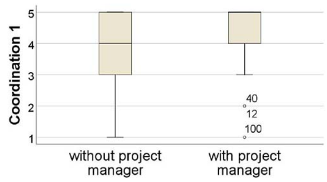

Fig. 2. Teamwork in well-coordinated fashion.

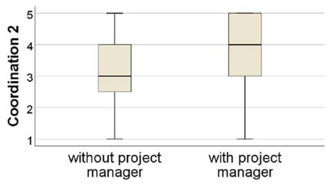

Fig. 3. Very few misunderstandings about what to do.

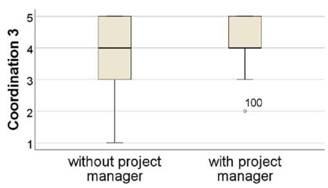

Fig. 4. Task accomplished smoothly and efficiently.

affect the project grade, a *t*-test was run (keeping the project grade as independent variable and whether the students have previously worked together as dependent) that did not show any statistically significant differences.

C. RQ3. The Effect of Project Manager

In order to examine whether the project manager affected TMS, a *t*-test was performed to compare the results of the two groups, i.e., with and without the presence of project manager(s). The difference is statistically significant for the case of coordination ($p = 0.001$). The students with a project manager gave a higher score in coordination ($M = 4.187$ and $SD = 0.609$ for students with project manager(s) in the team, and $M = 3.800$ and $SD = 0.749$ for students without). The scale items were also examined and it was observed that there is a statistically significant difference in the results. Students with a project manager indicated that the level of coordination in the team was better and that there were less misunderstandings in the team, whereas they found the way activities were accomplished slightly more efficient (item 1 of coordination: $p = 0.001$, item 2 of coordination: $p = 0.009$, and item 3: $p = 0.006$) as depicted in Figs. 2–4.

A considerable difference was also observed in the credibility ($p = 0.000$), with students in team with a project manager showing a higher credibility ($M = 3.998$ and $SD = 0.625$ for students with project manager(s) in the team, and $M = 3.541$ and $SD = 0.724$ for students without). The relevant descriptives are shown in Figs. 5–8, indicating that team members with project manager(s) within the team trusted more the knowledge and information coming from other team members, whereas they were less concerned about double checking information or not trusting their peers (item 2 credibility:

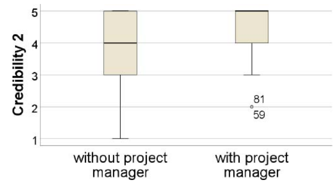

Fig. 5. Others' knowledge credible.

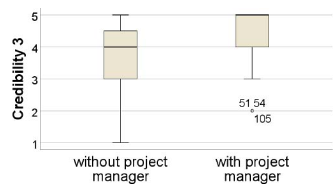

Fig. 6. Confident relying on information others brought.

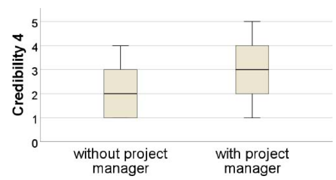

Fig. 7. Double check information from other members.

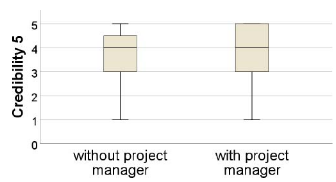

Fig. 8. Not much faith in others' expertise.

$p = 0.001$, item 3 of credibility: $p = 0.003$, item 4 of credibility: $p = 0.002$, and item 5: $p = 0.012$).

VI. Discussion

Students were generally positive about their collaboration (undergraduate and postgraduate level), as they were able to utilize the dynamics of the team in a better way with more space for task coordination and organization. This was also the outcome of the TMS analysis that did not reveal any significant shortcoming or problems in the team collaboration and communication in the TMS items. This indicates that team building with both undergraduate and postgraduate students can assist in the learning process for SE courses based on our experience. Overall, the TMS is present in the SE education and it seems that its parameters are well understood by students.

As a summary to RQ1, the specialization dimension of TMS has a lower mean than the other dimensions, indicating that overall the participants were less positive about their knowledge and the specialized knowledge of other team members, showing also that more emphasis needs to be put in this dimension. Moreover, postgraduates showed, as expected, more confidence in themselves than undergraduates. This is plausible considering the limited experience of undergraduates in the third year of their studies that may affect the degree they believe in the specialized knowledge they and their peers possess. Analyzing the effect of specialization on students at different level or year of studies may affect this result.

As a summary to RQ2, there were no significant gender differences in our sample. However, it is an interesting finding that female participants are slightly more comfortable accepting the knowledge of other members. Using a different instrument might reveal more and more significant gender differences. Prior collaboration and the project technological area have affected some subscales of TMS. For the case of the project type this shows that technical differences among projects is an issue that requires further investigation, and caution is needed when working with student teams that collaborate on projects with a variability in their technical requirements.

Regarding RQ3, the project manager has overall a positive effect on the teams, so assigning a project manager with more experience is advised. Specialization was not affected by any of the independent variables studied, indicating that specialized knowledge does not depend on the presence (or absence) of the project manager, or on the project type.

Overall, one important outcome of the above results is that the formation of a team within an SE course matters. The ability of the individuals that consist the team to trust the information shared within the team, are considered important for the successful completion of a task. Furthermore, the unique knowledge and skills that a student possesses can be useful for the rest of the team; however, the members should be aware and confident of their uniqueness and the uniqueness of others. The main conclusions drawn are summarized in the following.

1) The use of a student with more expertise acting as project manager in the team has a positive effect on how the team works.
2) The specialization dimension scores lower in the results and it is expected to encounter this also in other Universities, giving an indication that it is important to put more emphasis on the complementary of the students' skills and knowledge when creating the SE teams. This is not an easy task, since usually students follow the same study program and attend the same courses as in the case of the University of the current study, but a relevant questionnaire in the beginning of the semester can potentially assist in collecting relevant data to be considered. As concluded also in a previous work, specialization and credibility can have a positive influence on knowledge transfer [28]. The project type also needs to be considered in this respect and its mapping to existing knowledge, as differences in the TMS development for different technological areas were observed.
3) Tools that support coordination should be provided, potentially in the form of computer-aided SE (CASE) tools, although students demonstrated overall a higher score in this dimension.

VII. Limitations of the Study

The current study has a number of limitations mainly found in the small number of students that participated that may affect the *external validity* of the study referring to the extent the findings can be generalized. Although a larger number of students attended both courses, 305 students at bachelor and 31 at postgraduate level, only a subset of students participated in the study (52.08%), since participation was optional. It was thus, not feasible to collect feedback from all teams (the data concerns 43 out of 52 teams), and when a project manager existed she did not always participate in the survey (22 project managers participated out of the 27 teams with a project manager in total). Moreover, the study has been conducted in a specific cultural context. Replicating the study in a different setting may provide slightly different results.

Another limitation is that the SE courses considered are a third year undergraduate course and a postgraduate course. Students acquire skills gradually during their studies and it is expected that some of the conclusions or relationships found may differ, if undergraduate students in the first or second year of studies are considered.

The students that participated in this article attended the respective courses. This may have affected their responses, as they could believe that answering positively may have had a positive effect on their final grade in the courses, affecting thus, *construct validity* (the degree to which a test measures what it claims to be measuring). To remove this threat, the study was performed at the end of the semester and the students were informed that all data collected would be used for research purposes only and would be accessed after the courses and after the respective grading was finalized. The student responses were not known to the instructors until after grading the courses. It was also positive that the student experience from working in teams at the time they answered the survey was recent. Construct validity may have also been affected by the use of TMS. If a different measure was used, the results might have been slightly different.

Conclusion validity, i.e., the degree to which conclusions about the relationship among variables based on the data are correct, may have been affected in the project type analysis by the familiarization of the students with the technological area of the project (Web and mobile are, for instance, areas the students are better accustomed with than IoT). We have minimized this bias in the framework of the courses, as all teams could find a project on their own and they were graded on the same deliverables. Finally, the exact practical experience of the project manager (e.g., years employed) was not examined in this article.

VIII. Conclusion

In this article, an analysis of the effect of TMS on the SE students that collaborate in teams in the framework of SE courses has been presented revealing the positive impact of this collective process, taking into consideration different parameters. The concept of combining students of different levels of expertise within the same team was also introduced, in order to be able to assign the project management role within the teams.

Thus, work is expected to have an impact on the SE education research and practice, as it provides insights on the effect of TMS on SE education and can thus, help in recognizing its role in different educational environments, contributing to performing appropriate adaptations to courses and team formation in order to utilize the benefits of the TMS. It can also assist instructors in understanding better how the student teams perform and adapt the team composition in order to achieve better quality results from the team collaboration.

As future work in the framework of the courses, the authors intend to consider the use of different development models. The application of specific methodologies, such as scrum that has been widely adopted, will give space for different interactions among students [29]. However, this requires also a strict framework for examining the progress of the SE process that is harder to follow in the framework of a computer science curriculum. It would finally, be interesting to replicate the study in different cultural settings, in order to examine potential differences and perform a comparative analysis.

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