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Abstract: Collaborative problem-solving (CPS) is a fundamental skill for success in modern societies, and part of the most common constructivist teaching approaches. However, its effective implementation and evaluation are challenging for educators. Current inquiries on the identification of the observable features and processes of CPS are progressing at a pace in digital learning environments. However, still, most learning and teaching occurs in physical environments. In this paper, we present an original method for identifying differences in CPS behaviours when groups of students are taking part in face-to-face practice-based learning (PBL). Our dataset is based on high school and university students' hand position and head direction data, which can be automated deploying existing learning analytics systems. Our framework uses nonverbal indexes of students' physical interactivity (NISPI) in PBL in order to interpret the key parameters of synchrony, equality, individual accountability, and intraindividual variability. Our results show that interpretation of these parameters with the NISPI framework can be used to judge the CPS competency levels of groups accurately. In the past, concepts of equality, synchrony, and individual accountability have been investigated in online learning groups and asynchronous education settings. Here, we introduce the concept of intraindividual variability to the discussions of CPS. Furthermore, to our knowledge, this is the first attempt to automate the investigation of these parameters in face-to-face learning environments of PBL.

Opposed Reviewers:

# The NISPI framework: Analysing collaborative problem-solving from students' physical interactions

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# The NISPI framework: Analysing collaborative problem-solving from students' physical interactions

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## Abstract

Collaborative problem-solving (CPS) is a fundamental skill for success in modern societies, and part of the most common constructivist teaching approaches. However, its effective implementation and evaluation are challenging for educators. Current inquiries on the identification of the observable features and processes of CPS are progressing at a pace in digital learning environments. However, still, most learning and teaching occurs in physical environments. In this paper, we present an original method for identifying differences in CPS behaviours when groups of students are taking part in face-to-face practice-based learning (PBL). Our dataset is based on high school and university students hand position and head direction data, which can be automated deploying existing learning analytics systems. Our framework uses nonverbal indexes of students' physical interactivity (NISPI) in PBL in order to interpret the key parameters of synchrony, equality, individual accountability, and intraindividual variability. Our results show that interpretation of these parameters with the NISPI framework can be used to judge the CPS competency levels of groups accurately. In the past, concepts of equality, synchrony, and individual accountability have been investigated in online learning groups and asynchronous education settings. Here, we introduce the concept of intraindividual variability to the discussions of CPS. Furthermore, to our knowledge, this is the first attempt to automate the investigation of these parameters in face-to-face learning environments of PBL.

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9 **1. Introduction**

10 Collaborative problem-solving (CPS) is a fundamental skill for modern  
11 societies to function and it should be supported and practised in Educa-  
12 tion systems across the globe. Perhaps, as the significance of CPS is clear  
13 to most educators, it is part of many common constructivist teaching ap-  
14 proaches including problem-based learning, inquiry-based learning, project-  
15 based learning, and practice-based learning. It is common to see situations  
16 in which learners work in unison to solve a problem during these teaching ap-  
17 proaches, and perhaps that is why these constructivist teaching approaches  
18 are considered to have the potential to help foster the 21st-century skills we  
19 require of young people -including CPS-. For some decades now, there have  
20 been strong advocates of these teaching approaches in Education, arguing  
21 their merits in achieving such high-tier learning objectives [52, 6]. However,  
22 existing evidence on the effectiveness of these methods to satisfy their learn-  
23 ing outcomes is rare [34], and they have been harshly criticised by some  
24 researchers as not being effective pedagogical approaches [33, 46].

25 According to Blikstein and Worsley (2016), this lack of evidence may stem  
26 from these pedagogical approaches' notoriously dynamic and laborious struc-  
27 tures and commonly used standardised measurement method's lack of ability  
28 to detect impacts on students' skill development, including CPS. However,  
29 the most recent developments in sensor technologies and learning analytics  
30 methodologies can help generate unique information about what happens as  
31 groups of students are engaged in constructivist pedagogies. The distinctions  
32 between groups can be used to continuously evaluate and support students  
33 during their engagement with constructivist pedagogies. In this paper, we  
34 focus on CPS in practice-based learning activities and present the poten-  
35 tial of learning analytics research to generate and present salient features of  
36 high competency CPS behaviours in these open-ended, collaborative learning  
37 environments.

38 In order to make better sense of our results, it is important to make our  
39 understanding of CPS clear. Similar to the ideas of Panitz (1999), in this  
40 paper, our interpretation of collaboration is more of a philosophy of inter-  
41 action, in which individual group participants contribution is well respected  
42 and highlighted during the processes of problem-solving and knowledge con-  
43 struction. It is obvious to us that this approach differs from other group  
44 work approaches (including cooperation and peer tutoring) that are more  
45 formally structured to facilitate the creation of an end product or an aim.  
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9 It is also different from competition-based approaches in which individuals  
10 aim to outperform their teammates. All these different approaches might be  
11 valuable to consider for teachers as part of a broad pedagogical repertoire in  
12 order to achieve different learning outcomes of various learning contexts.  
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14 The rest of the paper is structured as follows: in the next section, we  
15 define what we understand by CPS in the context of this research work,  
16 discuss how it can be observed and define some key aspects of CPS to be  
17 investigated (namely, synchrony, individual accountability, equality and in-  
18 traindividual variability). Section 3 is devoted to the methodology used in  
19 our research, including the participants, learning activities and instruments  
20 of measure used. Then we present the results, followed by the discussion.  
21 The paper concludes with some conclusions and ideas for future research.  
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## 26 **2. About collaborative problem-solving**

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28 CPS is a term that is increasingly used to refer to the process of a number  
29 of persons working together as equals to solve a problem. It brings together  
30 thinking and research about the separate topics of collaboration and problem-  
31 solving, both of which have a substantial research history in their own right.  
32 CPS is more than individual problem-solving in the company of others. It  
33 involves a set of sophisticated interaction skills that need to be utilised at the  
34 same time in service of supporting, directing, facilitating and coordinating  
35 the thinking of others with ones own, to achieve a mutually agreed goal.  
36 There is a substantial relevant research literature, going back some 50-60  
37 years, across compulsory and post-compulsory education. This literature  
38 has used a range of different but overlapping terms including cooperative  
39 learning, collaborative learning, peer co-learning, peer tutoring, peer assisted  
40 learning as well as numerous other terms and phrases. Many authors have  
41 used these terms interchangeably, while others have tried to be quite distinct  
42 in how they define and describe them. Either way, it is very difficult to  
43 classify studies with respect to the different approaches referred to by this  
44 different terminology. However, it is worth discussing the constituent parts  
45 of CPS and ground it within the relevant wider literature concerning the  
46 associated concept of collaborative learning.  
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### 53 *2.1. A working definition of collaborative problem-solving*

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55 At a basic level, the verb to collaborate means to work together, and thus  
56 it assumes cooperation because participants agree to work together and con-  
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tribute to the interaction. Collaboration also assumes social coordination, because participants are sensitive and aware of the contribution made by others and the need to make their contributions pertinent and to coordinate their behaviour. But collaboration is more than this, it also involves participants working in unison as equals and oriented to a jointly agreed goal and often generating ideas that can form the basis for a possible solution or decision. Littleton and Mercer (2013) provide an eloquent account of collaborative learning that highlights some key features. These include that participants are engaged in a coordinated, continuing attempt to solve a problem or construct common knowledge; involved a coordinated joint commitment to a shared goal, reciprocity, mutuality, the continual (re-)negotiation of meaning. The participants are likely to experience a group sense or a feeling of shared endeavour; must establish and maintain intersubjectivity or recognising that they have a shared understanding about their endeavour; must maintain a shared conception of the task or problem; must engage in inter-thinking: understanding each others plans and actions.

Regarding the problem-solving on the other hand, OECD, 2010 defines it as an individuals capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve ones potential as a constructive and reflective citizen. A recent publication by Leadbeater (2016) sees problem-solving as a richer concept in which problem solvers: deploy knowledge in action, to work with others and to develop critical personal strengths such as persistence and resilience, to learn from feedback and overcome setbacks. This assumes collaboration as part of the problem-solving process, but helpfully also specifies the process as involving knowledge in action and overcoming setbacks. This resonates well with Marzano (1988), who has been highly influential on the OECDs definition and more widely in education. Marzano identified four knowledge utilisation processes: decision-making; problem-solving; experimental inquiry; and investigation.

Marzano described the process of problem-solving as happening when a learner attempts to accomplish a goal for which an obstacle exists (influenced by Rowe, 1985). Problem-solving requires the learner to use their existing relevant knowledge about the problem, retrieve prior knowledge, both about the subject matter of the problem and about the process of problem-solving, from memory that is relevant to the problem situation. The learner must identify the obstacle to problem solution, evaluate alternative goal and asso-

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ciated actions by processing information, select from these alternatives and put the selected goal oriented action into force.

As an overlap of these two key competencies from social and cognitive spaces, collaboration and problem-solving, the 2016 OECD PISA survey introduced the assessment of collaborative problem-solving (CPS) as part of their cycle of international assessments of 15-year-olds. Drawing most of the above considerations on collaboration and problem-solving, OECD defines CPS as Collaborative problem-solving competency is the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution [54]. However, even in their extensive and elaborate considerations on CPS, OECDs approach lacks to consider CPS as a multilevel process from different perspectives reflecting individuals, groups, and communities [22]. Furthermore, due to their main interests, OECDs approach to CPS is an assessment approach rather than broader consideration of CPS as a tuition approach [14]

## 2.2. *How to observe collaborative problem-solving?*

As it must be clear by now from the conceptual considerations discussed earlier, CPS is a complex process that requires implementation of multiple social and cognitive competencies. This makes its observation, to see whether the CPS is of quality or not, extremely challenging for educational researchers and practitioners. In the learning sciences literature, there have been certain mechanisms suggested through which CPS may influence cognition and support deeper learning. These are relatively more observable features and therefore may be useful in developing ways to evaluate and support CPS. They include students demonstrating an ability to:

1. articulate, clarify and explain their thinking [68];
2. re-structure, clarify and in the process strengthen their own understanding and ideas to develop their awareness of what they know and what they do not know [13, 32];
3. adjust their explanations when presenting their thinking, which requires that they can also estimate others understandings[3];
4. listen to ideas and explanations from others - this may lead listeners to develop understanding in areas that are missing from their own knowledge[36];

5. elaborate and internalise their new understanding as they process the ideas they hear about from others[15, 69];
6. actively engage in the construction of ideas and thinking as part of the co-construction of understandings and solutions [12, 28, 29, 67];
7. resolve conflicts and respond to challenges by providing complex explanations, counter evidence and counter arguments[4? , 31, 49];
8. search for new information to resolve the internal cognitive conflict that arises from discrepancies in the conceptual understanding of others [20, 30].
9. Establishing and maintaining shared understanding; taking appropriate action to solve the problem; establishing and maintaining team organisation[54].

Looking at the suggested mechanisms from the learning sciences above, it becomes clear that all the mechanisms presented above require investigation of complex verbal interactions of students. Hence, it is not surprising to see that most research in learning analytics aiming to investigate CPS focuses on investigating students verbal input in digital learning environments, including chat boxes [57], verbal interactions with online agents [50] and mobile tools that collect students written reflections on their CPS practices [39]. Nevertheless, such investigations are far from being straightforward. The investigation of complex CPS mechanisms through verbal indexes often require qualitative value judgments that are hard to validate, automate, and rely on. The verbal indexes are open to multiple interpretations regarding what mechanism or competency exactly do they belong to. Hence, they are also extremely hard to automate unless the potential interpretations are limited. Moreover, although verbal investigations are commonly conducted through sequencing of certain linear verbal actions, real-life CPS situations hardly fit in these linear sequences and occur often in more chaotic sequences. Furthermore, the transcription analysis of verbal indexes leads to losing important data of nonverbal actions and gestures. More recently, certain speech recognition technologies in verbal indexes are used to overcome some of those issues that relate to the use of verbal indexes in investigation of CPS in real-life environments, nevertheless they are not sensitive and accurate enough to be applicable in real classroom settings yet, particularly in dynamics and noisy classroom environments of PBL. It goes without saying that the oral language is a valuable source to investigate students learning mechanisms including CPS, however, we argue here that nonverbal contributions are also



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9 valid and in some cases might even reflect more genuine observations of stu-  
10 dents intentions and ideas.  
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### 12 *2.3. Investigated aspects of collaborative problem-solving*

14 CPS has various aspects that need to be taken into account in discussions  
15 of the process. In this paper, we focus on four key aspects that we derive from  
16 learning sciences literature on collaboration and problem-solving. These are  
17 not the only aspects of CPS, however, they are important aspects of CPS  
18 and they have the potential to be interpreted through nonverbal indexes of  
19 students physical interactivity: synchrony, individual accountability, equal-  
20 ity, and intraindividual variability. In this section, we briefly define these  
21 concepts and explain how do they relate to CPS.  
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#### 24 ***Synchrony***

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26 The quality of the collaboration is related to the quality of the relation-  
27 ships of the students within the groups [35]. This quality of the relationships  
28 is dependent on multiple aspects of group dynamics including reciprocity,  
29 impressions about others in the group, the feeling of being a community  
30 with other group members, and the perceptions about mutual dependency  
31 to achieve the aim [35]. Some of these psychosocial processes of social in-  
32 teractions might be interpreted through observation of students physical in-  
33 teractions. For instance, students who collaborate and get on well, show a  
34 high level of behavioural mirroring which then leads to high level of syn-  
35 chrony among group members [64]. This synchrony, in turn, leads students  
36 to attributions of rapport and entitativity, which are significant indicators of  
37 high collaboration groups. As the previous research shows when people try  
38 to get along with another person, which is an important criterion for suc-  
39 cessful collaboration, they mimic the other person strongly [10]. Similarly,  
40 in workplace and military environments, when groups are working well, they  
41 appear to converge their actions such that they move in unison [37, 38]. In  
42 the learning analytics research context, Schneider and Pea (2013) found that  
43 students visual synchrony, measured with eye-trackers, positively correlated  
44 with students learning gains. However, this finding was contradicted when  
45 it came to students body synchronisation. Schneider and Blikstein (2015)  
46 found that even though gaze synchrony can be a strong predictor of student  
47 learning, body synchrony may not hold the same properties.  
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#### 50 ***Individual Accountability***

51 Individual accountability refers to students making sure that they under-  
52 take their share of the work and feel personally responsible for the groups  
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9 success while others are also undertaking their share in completing the task.  
10 As argued by Slavin (1991) in his synthesis of research so far undertaken  
11 in the domain, group goals and individual accountability are the two key  
12 features of any successful group work. In groups that present high collabo-  
13 ration, students engage in promotive interaction and show a willingness to  
14 support each other in their joint efforts to complete the task and achieve the  
15 goal. Therefore there appear to be two main requirements of individual ac-  
16 countability 1) students should undertake their share in completing the task,  
17 2) each students share is promoted and acknowledged by other members of  
18 the group. In a learning analytics context, individual accountability is often  
19 considered to be measured with the amount of input generated by individ-  
20 ual students. This satisfies the first requirement of individual accountability.  
21 However, also individual students promotion and acknowledgement should  
22 be taken into account in considerations of individual accountability.  
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### 24 ***Equality***

25 Equality is considered to be an important aspect of CPS by most educa-  
26 tional researchers. For instance, early research by Damon and Phelps (1989)  
27 argue that equality and mutuality are two significant indexes student inter-  
28 action that can be used to distinguish between high collaboration approaches  
29 from other types of peer learning including peer tutoring and jigsaw types  
30 of cooperative learning activities. Equality refers to a situation where par-  
31 ticipants are equal in status and participate in a two-way dialogue taking  
32 direction from one another, whilst mutuality refers to a situation where high  
33 mutuality means that discourse is extensive, intimate and connected. As  
34 argued by Damon and Phelps (1989) peer tutoring tends to foster dialogues  
35 that are relatively low on equality and varied in mutuality; cooperative learn-  
36 ing foster ones that are relatively high in equality and low to moderate in  
37 mutuality; and collaboration fosters ones that are high in both. More recent  
38 researchers echo similar ideas. For instance, Dillenbourg, Lemaignan, San-  
39 gin, Nova, and Molinari (2016) use the concept of symmetry and argue that  
40 collaborative learning requires some sense of symmetry in terms of students  
41 knowledge and skills as well as their contribution to interactions, and their  
42 status.  
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### 44 ***Intraindividual variability***

45 As emphasised by various other researchers CPS tends to be inherently  
46 interactive, interdependent, and dynamic [8, 70]. CPS can only occur if the  
47 students attempt to create a common ground about the problem/task they  
48 are dealing with [11]. The establishment of such shared understanding oc-  
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curs through students communication and interaction with each other about the meaning of the problem/task. Creation of a common ground among group members is based on students ability to understand behaviours, cognitions, and attitudes of other participants and oneself; and to translate this understanding into appropriate behaviour in social situations [44]. In this dynamic context, the establishment of a common ground involves continuous correction of students performance based on reactions of others during social exchanges [2]. This continuous correction and change in behaviours require a dynamic systems approach [65] to students physical interactions, as dynamic systems approaches are ideally suited to describing the complex and constantly evolving patterns of students actions [43]. The dynamic system approaches are not new in educational research, however, their application requires an intensive and detailed observation of students interactions while they are solving problems collaboratively and, this is extremely challenging using the traditional educational research methods. Nevertheless, the emergence of the multimodal learning analytics research field provides various new methodologies and technologies to collect intensive, sequentially repeated measures of real-time data in real-life contexts. We take advantage of such advancement in research methodologies and technologies, to investigate intraindividual variability aspect of CPS. Intraindividual data is derived from single individuals across multiple variables and multiple occasions and have been used in the past to make sense of numerous dynamic educational constructs including students cognitive changes [51, 59]; their language development [66]; social-emotional development [41]; and students self-regulatory behaviours [48]. In this research paper, we investigate the intraindividual variability of students physical interactivity as another potentially important aspect of CPS. To our knowledge, such investigation has not been attempted before.

### 3. Methodology

The overarching research aim of this study is to investigate the four aspects of CPS via nonverbal indexes of students physical engagement. This aim was shaped into two main research questions:

- RQ1) What are the observable pattern differences between groups, in terms of their nonverbal indexes of physical interactivity related to the synchrony, equality, individual accountability, and intraindividual variability aspects of CPS?

- RQ2) What aspects of CPS represented with nonverbal indexes of physical interactivity, are good predictors of high CPS groups?

### 3.1. Participants

The participants were forty-five students, of which nine are in the first year of their secondary education (aged 11-12 years) from a girls-only secondary school in the UK, and the other thirty-six are Engineering students at a European University, with an average age of 20 years old, mixed gender. The study does not involve any primary school students in order to safely assume that all students have sufficient cognitive and social abilities for abstract thinking [56] and perspective taking [24]. Participating high school students were recruited from a computer science class and selected by their teacher out of a class of thirty students based on their success in computer science. Engineering students were selected by their lecturers based on their success in programming courses. The teachers and the lecturers were asked to pick an even balance student ability as far as was possible, to ameliorate the bias of existing knowledge and skill differences between students on their CPS performances. The existing research shows that CPS to certain extent rely on domain knowledge [47, 26]. Our aim was to create groups that are symmetrical with respect to knowledge, status, and goals [17]. We obtained written consent from students and their parents/guardians for high school students, in line with our institutions ethics procedures.

### 3.2. Learning Activities

Next, we describe the learning activities for high school and university students.

#### **Learning activity for high school students**

Students were set the task of building a working prototype using an Arduino-based physical computing kit, called TALKOO. The TALKOO kit comprises hardware modules, a visual IDE and prototyping material [63]. Sensor and actuator modules are pluggable, do not require soldering, and no prior knowledge in electronics is needed. The components have the ability to talk back to the visual IDE and to a learning analytics system. The students were also provided with craft materials (coloured paper, paper cups, wooden sticks, glitter, glue, etc.) with which to create their working prototypes in combination with the physical computing kit. The study involved two sessions that were run two days apart.

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- **Session 1** took place in the schools IT (Information Technologies) lab, during school hours, and involved the entire class of thirty students. The session lasted for 1 hour and 20 minutes, during which students worked with a TALKOO kit in pairs or groups of three. The purpose of Session 1 was for students to familiarise themselves with the physical computing kit through a number of predefined activities that exemplified the function of specific components (RGB light, temperature sensor and potentiometer) and logic functions (if statement, mapping function and switch function). A researcher, who was assisted by three colleagues and the class teacher, ran session 1.
  - **Session 2** took place at the university and involved nine students from the same class as Session 1. The participants were grouped into three groups of three students, and each group was identified with a different name. The students were grouped by their teachers based on their previous experiences. The session lasted about four hours and involved:
    1. A refresher session, during which students worked through predefined activities that exemplified the functions of components and logic functions (as in Session 1) - 30 minutes
    2. An open-ended activity to build an interactive toy 2 hours
    3. A brief activity to demonstrate the function of a motor 15 minutes
    4. An open-ended activity to build an artefact using a motor 1 hour
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Activities 1 and 3 were led by a researcher, who demonstrated how to connect and program the components. During activities 2 and 4 groups of students worked independently, but supported by an adult, who assisted them with troubleshooting the TALKOO kit and debugging the visual programming when/if needed. Only the data that is collected during the activities 2 and 4 is analysed in this research work.

### 47 48 49

#### **University Students Learning Activity**

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University students used exactly the same kit and the learning analytics system in their learning activities. However, due to the complexity of their programming and designs, they were allowed to work through the project system hardware, software and desk over 3 days, to complete 3 open-ended tasks.

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Similar to the high school students, in an initial session, the university students were introduced to the system and the physical computing kit using

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9 a relatively simple introductory task. This is identical to the session 1 of the  
10 high school students, hence will not be repeated here. In the second session,  
11 students were asked to design and prototype an interactive toy (similarly to  
12 the task for the high school students). No specific instructions about the  
13 timing of these phases were given to students, and sessions lasted between  
14 33 and 75 minutes (with the median of 63 minutes). The participants were  
15 grouped into twelve groups of three students, and each group worked on all  
16 three tasks and was identified with a different name.  
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### 20 *3.3. The NISPI framework for analysis*

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22 In this section, we describe the instruments of measurement we have used  
23 and the research variables we have defined to formulate the NISPI framework.  
24

#### 25 **NISPI - Nonverbal Indexes of Students Physical Interactivity**

26 First, we describe the coding scheme we created in order to generate  
27 meaningful nonverbal indexes of students physical interactivity. The coding  
28 scheme makes use of three digits, 0, 1 and 2 to represent passive, semi-active  
29 and active student states. The active code (2) was used whenever a student's  
30 hand was active with an object; the semi-active code (1) was used when a  
31 student was not physically active, but their head was directed towards a  
32 peer (or the facilitator) who was active or to an object that was part of the  
33 learning task, and the passive code (0) was used in the rest of situations.  
34 Students behaviours were coded using thirty-second windows. There are two  
35 main features of the coding scheme we created. First, it is simple enough  
36 to be automated with the existing learning analytics system we created as  
37 part of an EU-funded project (see the project blinded for review). Second,  
38 it is comprehensive enough for us to interpret the key aspects of CPS we  
39 discussed earlier. To represent the groups, we use the following notation: the  
40 twelve university groups have been named Univ. n, where n=A,...,L, while  
41 high school groups have been named Hsch. m, where m=1,2,3. Given a  
42 group G, its students are represented by a variable G-s, where s takes values  
43 1, 2 and 3. Let us define the interactivity index for a student s in certain  
44 group G Univ. A,...,Univ. L, Hsch. X, ,Hsch. Z as a variable that takes  
45 values 0,1, 2 and is given by:  
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$$52 \text{ AI } (s_i, t) = \text{Activity code of student } s_i \text{ of group } G \text{ at time } t, \text{ where } i = \\ 53 \text{ 1,2,3; and } t = 30, 60, \dots \\ 54 \\ 55 \\ 56 \\ 57 \\ 58$$

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Given a group of students working together, the situation at any given moment is coded by concatenating the values of the activity codes for each student.

To exemplify this coding scheme, let us consider the situations pictured in Figures 1 and 2.



Figure 1: University students working on a project



Figure 2: High school students working on a project

For the situation shown in Figure 1, in our approach it is coded as 2 (student on the left) 1 (student at the centre) and 1 (student on the right), i.e., 211. Similarly, the situations on Figure 2 would be coded as 012, 121, 022 and 202, respectively (from left to right and from up to down)

To validate the coding situations, two coders applied this coding scheme to all groups video data using 30-second windows. This procedure was used as a way of testing the reliability of the coding system generated. Whenever there was disagreement, the researchers discussed the data and revised their coding accordingly.

### Using Nonverbal Indexes of Students Physical Interactivity to Interpret Key Aspects of CPS

The use of active, semi-active and passive codes provides 27 potential positions in which three students working together could be at any particular point in time. We categorised these positions into groups of 10 situations and then identified potential representations of the key aspects of CPS discussed earlier (see table 1 below).

Potential positions of three students CPS	Categorised situations of three students CPS
000	Only 0s (000)
100, 010, 001	Two 0, one 1 (001)
200, 020, 002	Two 0, one 2 (002)
011, 101, 100	Two 1, one 0 (011)
012, 021,102,120,201,210	One of each (012)
111	Only 1s (111)
002, 020, 200	One 0, two 2s (022)
112, 121, 211	One two, two 1s (211)
122, 212, 221	One 1, two 2s (221)
222	Only 2s (222)

Table 1: Positions, situations and predictors

**Synchrony:** The investigation of the concept of synchrony using students nonverbal indexes of physical interactivity was the most straightforward one because the concept of synchrony dictates us to take into account three categories of situations: 000,111,222. In our calculations, we considered 222 as a sign of active synchrony in which all three students are physically active. 111 was used to calculate the total amount of support the group received from a human resource outside the group (the teacher, the facilitator, another student from another group etc.). Finally, 000 indicates the total amount of time that students spent completely off the topic.

In particular, we defined a research variable to account for positive synchrony in each group. This variable is defined as:



Syn(G) = percentage of 222 states in group G

**Individual Accountability:** As we discussed earlier, individual accountability fundamentally depends on each students undertaking their share in completing the task and the promotion and acknowledgement of each students contribution to the workload. We investigate whether each student contributes to their share of the workload as part of equality concept through their mean values of physical interactivity scores. In order to interpret students promotion and acknowledgment of each others contribution, we added the percentage of those situations in which at least one member student is purposefully observing the action taken by a member of the group (221+211) and subtracted those situations in which at least one student is ignoring an action taken by a member of the group (220, 210, 200). That is, we define the variable:

$$IA(G) = \text{percentage of } (211, 222) - \text{percentage of } (002, 012, 022)$$

Our hypothesis is that these moments might have the potential to reflect students individual accountability values, as they represent those moments in which an individual students initiative to take action is valued and promoted by at least one other peer.

**Equality:** In order to investigate the extent to which the degree of equality observable in students physical interactivity can be used as a nonverbal index to interpret CPS, we looked at the mean activity indexes of each students AI (G-s, G, t) as defined above. In particular, we have considered the mean activity index for each student, the standard deviations, the average mean score and the total squared differences in the mean scores. In particular, the formula we have used for the computation of total square difference in a group G of students s1, s2, s3 is given by:

$$Totalsq.diff(G) = \sum_t [(AI_{(s_1,t)} - AI_{(s_2,t)})^2 + (AI_{(s_1,t)} - AI_{(s_3,t)})^2 + (AI_{(s_2,t)} - AI_{(s_3,t)})^2]$$

**Intraindividual variability:** The importance of creating a common ground in effective CPS process through dynamic communication and interaction, and the potential of intraindividual variability to measure such dynamic systems were discussed earlier in the paper. Our hypothesis here is

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9 that during the course of practice-based learning activities, students intrain-  
10 dividual variability of physical interactions may reflect the level of shared  
11 experience as a group. Intraindividual variability refers to the amount of  
12 change in the behaviour of a student  $s_i$  between two sequential time windows  
13  $t_k$  and  $t_{k+1}$ , and it is defined by:  
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$$18 \quad IV_{(s_i)} = \frac{\sum_{k=1}^{N-1} (AI(s_i, t_k + 1) - AI(s_i, t_k))^2}{19 \quad N - 1}$$

### 20 21 22 **Human Observer Analysis of Collaborative Problem-solving**

23 In order to create an independent variable to test our hypotheses pre-  
24 sented above, human observers, who are experienced teachers, were asked to  
25 judge groups CPS using an analysis framework [14], based on OECDs assess-  
26 ment framework of CPS [54]. The analysis framework has three key dimen-  
27 sions of collaboration (Establishing and maintaining shared understanding,  
28 Taking appropriate actions to solve the problem, Establishing and maintain-  
29 ing team organisation), and six key dimensions of problem-solving (Identify-  
30 ing facts, Representing and formulating knowledge, Generating hypotheses,  
31 Planning and executing, Identifying knowledge and skill deficiencies, Mon-  
32 itoring, reflecting and applying). Each group was observed with a human  
33 observer who watched students working on the learning activity and used a  
34 mobile tool to mark the critical incidents that relate to the key dimensions  
35 of collaboration and problem-solving as they occur. Based on their human  
36 judgement and teaching experience, human observers ranked groups as high,  
37 medium and low-level CPS groups. In order to ensure high agreement among  
38 observers, they are trained in a daylong, hands-on workshop about the CPS  
39 competencies and the CPS analysis framework. In this workshop, they were  
40 trained on the meaning of each competency and how they could potentially  
41 be judged in CPS. This ranking is used as an independent variable to shape  
42 the presentation of the results and arguments in this paper. Table 2 below  
43 shows the results of the human observers evaluation of groups CPS levels.  
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50 Note that group Univ-A has not been classified in terms of the quality of  
51 their CPS. The reason is that the behaviour of the group was abnormal due  
52 to a technical problem with the visual programming tool of the group. The  
53 facilitator spent a lot of time to fix the visual programming tool of the group,  
54 while the group members were observing the facilitator. For the sake of data  
55 completeness, we have decided not to leave this group out the analysis for the  
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High Competency CPS Groups	Med. Competency CPS Groups	Low Competency CPS Groups
Univ. D, Univ. F, Univ. J	Univ. C, Univ. E, Univ. G, Univ. H, Univ. I, Univ. L	Univ-B, Univ-K
Hsch X	-	Hsch Y, Hsch Z

Table 2: Summary of human evaluations of students CPS competencies

different indicator values, but results of Univ. group A should be interpreted with caution.

#### 4. Results

In this section, we present the observational pattern differences in the four key aspects related to CPS, represented via indexes of students physical interactivity.

**Synchrony:**

Table 3 below represents the percentages of different categories of situations. synchrony states are labelled as SYN, and the active synchrony state (222) and individual accountability states are coloured bold. As explained before, individual accountability is computed by adding the percentages of situations in which at least one student actively observes a physically active student (221, 211) minus the percentages of situations in which at least one student does not actively observe a physically active student (002, 012, 022). High CPS groups are shaded in dark grey, while low CPS groups are shaded light grey.

The respective percentages of synchrony for university and high school students groups present clear differences. The results show that, on average, high CPS university students appear to spend relatively more time in active synchrony in comparison to high school students groups. Perhaps more importantly, the results show that most groups spent very little time completely off-task in 000 synchrony. University groups Univ-B and Univ-I have the highest percentage of off-topic time spent among all groups. As the results of the SYN 111 show, most groups did not receive a whole group intervention from the teachers, lecturers, or facilitators. The notable exception here is that of group Univ-A. This group spent almost a third of their time receiving a group intervention from a facilitator (30.88%), due to a technical

	SYN 000	SYN 111	001	002	011	012	022	IA 211	IA 221	SYN 222	Ind_Account
Univ. A	0,00%	30,88%	0,00%	0,00%	1,47%	1,47%	0,00%	47,06%	19,12%	<b>0,00%</b>	<b>64,71%</b>
Univ. B	4,55%	0,00%	0,00%	16,36%	0,00%	10,91%	8,18%	23,64%	26,36%	<b>10,00%</b>	<b>14,55%</b>
Univ. C	5,26%	1,05%	0,00%	13,68%	1,05%	6,32%	9,47%	21,05%	25,26%	<b>16,84%</b>	<b>16,84%</b>
Univ. D	0,00%	7,14%	0,00%	0,00%	0,00%	1,95%	5,19%	18,18%	29,22%	<b>38,31%</b>	<b>40,26%</b>
Univ. E	0,00%	0,00%	0,63%	1,27%	0,00%	8,86%	8,23%	17,09%	37,97%	<b>25,95%</b>	<b>36,71%</b>
Univ. F	0,00%	0,65%	0,00%	0,00%	0,00%	0,00%	3,90%	13,64%	33,12%	<b>48,70%</b>	<b>42,86%</b>
Univ. G	0,72%	3,62%	0,72%	2,90%	1,45%	8,70%	5,07%	31,88%	32,61%	<b>12,32%</b>	<b>47,83%</b>
Univ. H	6,40%	0,00%	0,00%	12,00%	0,00%	11,20%	11,20%	8,00%	26,40%	<b>24,80%</b>	<b>0,00%</b>
Univ. I	7,35%	0,00%	0,00%	11,03%	0,00%	7,35%	9,56%	8,82%	25,74%	<b>30,15%</b>	<b>6,62%</b>
Univ. J	0,00%	2,97%	0,00%	0,00%	0,00%	0,00%	0,00%	12,87%	40,59%	<b>43,56%</b>	<b>53,47%</b>
Univ. K	4,17%	1,67%	2,50%	8,33%	2,50%	16,67%	8,33%	25,83%	18,33%	<b>11,67%</b>	<b>10,83%</b>
Univ. L	0,94%	0,00%	0,00%	3,77%	0,94%	8,49%	7,55%	28,30%	25,47%	<b>24,53%</b>	<b>33,96%</b>
HSch. X	2,63%	7,24%	1,32%	3,29%	0,66%	5,92%	3,29%	23,03%	27,63%	<b>25,00%</b>	<b>38,16%</b>
HSch. Y	0,00%	0,00%	1,54%	6,15%	1,54%	13,85%	12,31%	18,46%	26,15%	<b>20,00%</b>	<b>12,31%</b>
HSch. Z	2,02%	0,00%	3,03%	11,11%	1,01%	12,12%	24,24%	3,03%	19,19%	<b>24,24%</b>	<b>-25,25%</b>

Table 3: Percentages of different situations for the total groups

problem with the visual programming tool. It is worth noting that all high school groups spent very little or no time observing a facilitators intervention.

If we look at the results of those groups which were identified as high CPS groups by human observers (groups Univ-D, Univ-F, Univ-J and Hsch-X), we can clearly see a pattern of high 222 percentages. The three high CPS university groups have the highest three percentage values of active synchrony. On the other hand, those groups which were identified as low CPS by human observers appear to present much lower percentages of active synchrony. Looking at these results, the available evidence indicates a positive correlation between the level of CPS and the amount of active synchrony in groups. That is worth further investigation at a larger scale to see how such differences hold in big sample sizes. In other studies, results have shown that synchrony can be a good indicator of effective collaboration in some circumstances (such as students gaze [61]) and it may not reflect collaboration in some others (such as body synchronisation [60]). Our results suggest that groups active synchrony data is a potential indicator of collaboration in problem-solving. The variances in results in the literature may be due to the number of students in the groups studied (since dyads and triads might have different dynamics), and whether the students are in the same physical space or not.

**Individual Accountability:** As for individual accountability, table 3 shows some interesting results. The high CPS groups appear to have high percentages of individual accountability (42.86%, 40.26%, 53.46% and 38.16% for groups Univ-F, Univ-D, Univ-J and Hsch-X, respectively), whereas low

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CPS groups appear to have low individual accountability values (for Univ-B it is 11.49%, for Univ-K is 10.53%, and for Hsch-Z is -25.25%). However, there are also other data inputs that do not align with such observations. For instance, for groups Univ. A and Univ. G, even though were not considered as a high CPS group by human observers, their individual accountability value measured in our calculations are quite high with the respective values of 64.71% and 47.83%. These results may stem from various reasons. First of all, as we mentioned earlier group As results might be skewed due to the unusual level of facilitator support provided. Second, individual accountability as we defined it, might not reflect CPS. Third, our coding scheme and calculations can not capture the level of individual accountability in groups. Based on these results we argue that the concept of individual accountability and its measurement through nonverbal indexes of physical interactivity require further improvements to be effectively used in investigations of CPS.

**Equality:** Regarding the equality, we first investigated the extent to which the degree of equality observable in students physical interactivity.

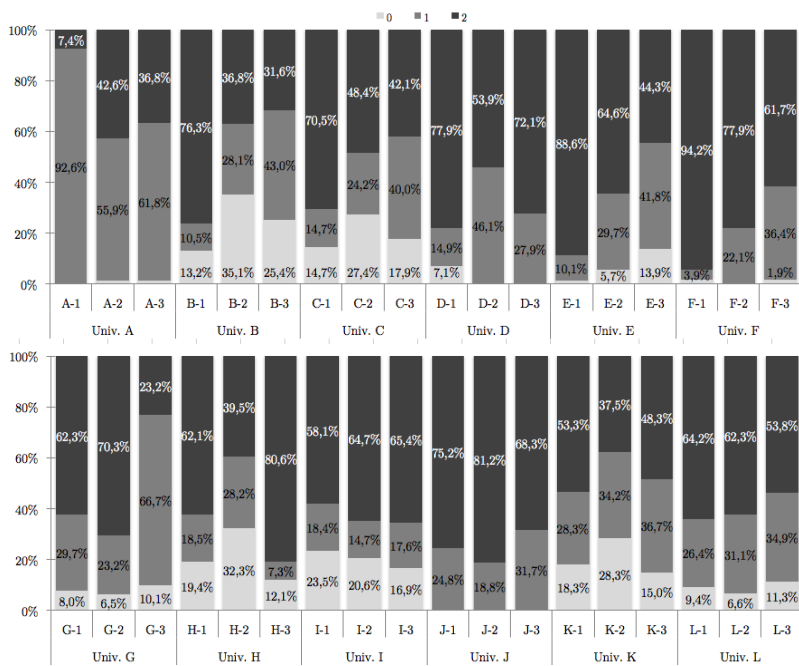


Figure 3: Percentages of individual students number of passive 0, semi-active 1, and active codes 2 in university groups

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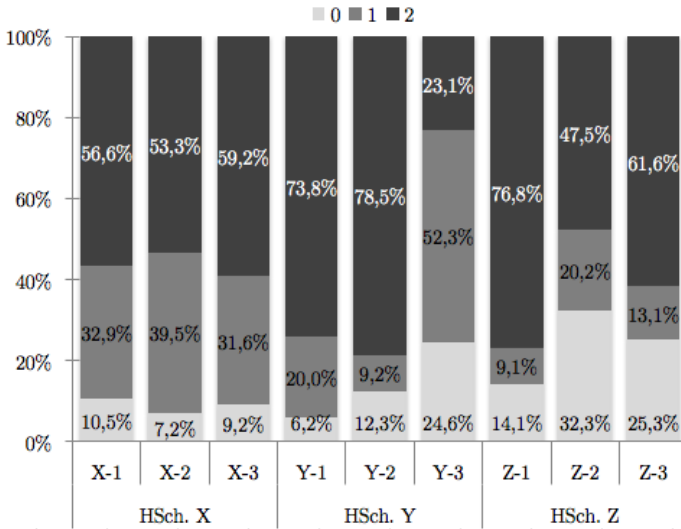


Figure 4: Percentages of individual students number of passive 0, semi-active 1, and active codes 2, in high school groups

Figures 3 and 4 illustrate that some groups showed more equality (e.g. Univ. I, Univ. J, Univ. D and Hsch. X) than others. It shows that the distribution is irregular for some groups (e.g. groups Univ. B, Univ. K, Univ. E) and identifies the students who were more physically active (e.g. student F-1 in Univ. F, or student Y-2 in HSch. Y) and students who were less physically active (e.g. student A-1 in Univ. A or student A-3 in Hsch.Y). In order to have a better idea about the equality of students physical interactivity, we looked at the mean scores of their codes. Table 2 presents these results and indicates in dark grey the groups which were identified by the observer as high CPS groups (U-Groups D, F and J and S-Group X). The groups identified as low CPS are indicated by a lighter shade of grey (U-groups B and K, S-groups Y and Z).

As the results above show, those groups coded as high CPS groups by human observers had higher mean scores for physical interactivity than those coded as low CPS groups. Considering the practice-based structure of the learning activity these results are not surprising. However, a finding that becomes clear from table 2 is that the groups rated as high CPS groups have member students whose physical interactivity mean scores are similar. By contrast, the groups rated as low CPS groups have member students whose mean scores for the physical interactivity of each student are more varied.

	Univ. A			Univ. B			Univ. C			Univ. D			Univ. U			Univ. F		
Student	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3	D-1	D-2	D-3	E-1	E-2	E-3	F-1	F-2	F-3
Mean AI	1,07	1,41	1,35	1,71	1,07	1,12	1,63	1,29	1,33	1,70	1,60	1,75	1,87	1,60	1,31	1,92	1,78	1,60
Sd AI	0,26	0,53	0,51	1,71	1,07	1,12	0,64	0,78	0,65	0,61	0,49	0,43	0,37	0,59	0,70	0,33	0,42	0,53
av. Mean	1,28			1,30			1,41			1,68			1,59			1,77		
Total sq diff	0,20			0,76			0,21			0,04			0,47			0,16		
	Univ. G			Univ. H			Univ. I			Univ. J			Univ. K			Univ. L		
Student	G-1	G-2	G-3	H-1	H-2	H-3	I-1	I-2	I-3	J-1	J-2	J-3	K-1	K-2	K-3	L-1	L-2	L-3
Mean AI	1,54	1,64	1,13	1,45	1,10	1,71	1,43	1,55	1,58	1,75	1,81	1,68	1,35	1,09	1,33	1,55	1,56	1,42
Sd AI	0,64	0,60	0,56	0,77	0,83	0,63	0,77	0,72	0,67	0,43	0,39	0,47	0,77	0,81	0,73	0,66	0,62	0,69
av. Mean	1,44			1,42			1,52			1,75			1,26			1,51		
Total sq diff	0,44			0,57			0,04			0,02			0,13			0,03		
	HSch. X			HSch. Y			HSch. Z											
Student	X-1	X-2	X-3	Y-1	Y-2	Y-3	Z-1	Z-2	Z-3									
Mean AI	1,46	1,46	1,50	1,68	1,66	0,98	1,63	1,15	1,36									
Sd AI	0,68	0,63	0,66	0,59	0,69	0,70	0,72	0,88	0,86									
av. Mean	1,47			1,44			1,38											
Total sq diff	0,00			0,94			0,34											

Table 4: Active mean scores, averages and total squared differences across groups

For instance, in U-Group J, which was coded as a high CPS group, the mean scores for the member students physical interactivity were 1.75, 1.81, and 1.68; and the total squared differences the three students physical interactivity scores was 0.02. On the other hand, the mean physical interactivity scores for member students of U-Group B, which was coded as one of the low CPS groups, were 1.07, 1.12, and 1.71, and the average of the differences between the three students physical interactivity was 0.76. The difference in physical interactivity scores for group B is approximately forty times bigger than the average differences in the high collaboration group J. We can also use triangle visualisations to represent this data. The triangles shown in Figure 5 were drawn using the activity mean scores as the height values of A, B, and C points, for the students in groups Univ. D (high CPS) and Univ. K (low CPS), i.e. for the first triangle  $h_a=1.70$ ,  $h_b=1.60$ , and  $h_c=1.75$ , and for the second triangle (U-group K)  $h_a=1.35$ ,  $h_b=1.09$ , and  $h_c=1.33$ .

As we can see, the triangle for the high CPS competency group (Univ. D) appears to be more equilateral than the one for the low CPS competency group (K). For instance, If we calculate  $k$  value as the distance between the orthocentre and the barycentre, we can see that this distance is much larger for low CPS groups ( $k=0.13$  for Univ. D and  $k=0.3$  for Univ. K). Such triangular visualisations can perhaps be used to present the performance of each group to students and teachers in CPS. Students can use them to

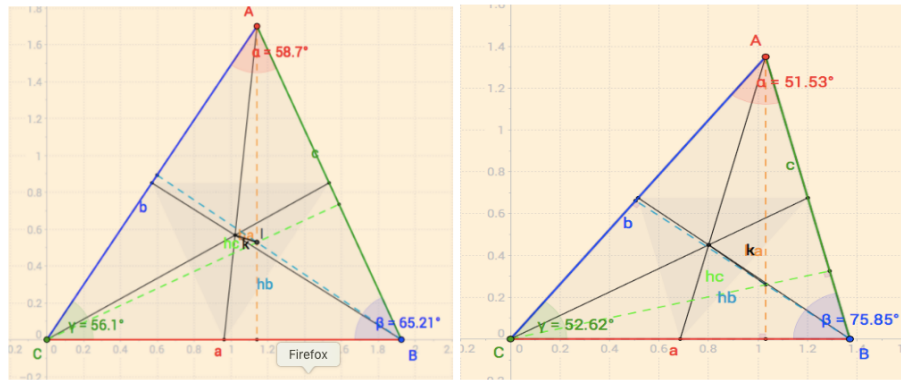


Figure 5: The visual representation of equality of students physical interactivity (Group D and Group K)

reflect on their practice, and teachers can use them to shape and time their interventions. For instance, if such information is provided to teachers in real-time, they can prioritise their interventions to these groups that have the highest  $k$  values. In addition to helping teachers time and prioritise their interventions, these visualisations may help them to shape their interventions. Teachers would scaffold groups so that the  $k$  distance would be shortened. For group Univ. K in fig 5. the intervention would require the teacher to stimulate student 2 to be more engaged in the learning activity.

**Intraindividual variability:** As discussed earlier, we consider the mean squared differences as a good method to calculate students intra-individual variability (IV), as it represents the mean value of the total amount of changes in students physical interactivity.

	Univ. A			Univ. B			Univ. C			Univ. D			Univ. U			Univ. F		
Student	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	C-3	D-1	D-2	D-3	E-1	E-2	E-3	F-1	F-2	F-3
IV	0,54	0,61	0,83	0,52	0,61	0,84	0,68	0,89	0,51	0,29	0,27	0,24	0,27	0,53	0,42	0,20	0,25	0,38
Total sq diff	0,14			0,16			0,22			0,00			0,10			0,05		
	Univ. G			Univ. H			Univ. I			Univ. J			Univ. K			Univ. L		
Student	G-1	G-2	G-3	H-1	H-2	H-3	I-1	I-2	I-3	J-1	J-2	J-3	K-1	K-2	K-3	L-1	L-2	L-3
IV	0,60	0,41	0,63	0,73	0,79	0,46	0,77	0,58	0,72	0,22	0,22	0,27	0,98	0,92	0,43	0,82	0,60	0,54
Total sq diff	0,08			0,19			0,06			0,01			0,55			0,13		
	HSch. X			HSch. Y			HSch. Z											
Student	X-1	X-2	X-3	Y-1	Y-2	Y-3	Z-1	Z-2	Z-3									
IV	0,74	0,57	0,73	0,67	0,84	0,83	0,84	1,18	1,49									
Total sq diff	0,06			0,05			0,64											

Table 5: IV scores and total squared differences in IV of groups



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The table 5 below shows the intraindividual variability and total squared differences values for university and high school groups. Results show that high CPS groups show lower IV values, whereas low CPS groups show higher IV values. If we look at the total squared differences of individual students IV scores in groups, high CPS groups appear to have low values (Univ. D= 0.00, Univ. F= 0.05, Univ. J= 0.01, Hsch.X = 0.06), whereas low collaboration groups have the highest two figures (Univ. B= 0.16, Univ. K= 0.55, HSch. Z=1.49). The low IV values can be achieved if students continue their level of physical interactivity for longer periods of times, rather than having frequent changes in their interactivity. Figure 6 illustrates the chronological changes in IV values for groups Univ. F and Hsch. X (high CPS) and Univ.K (low CPS).

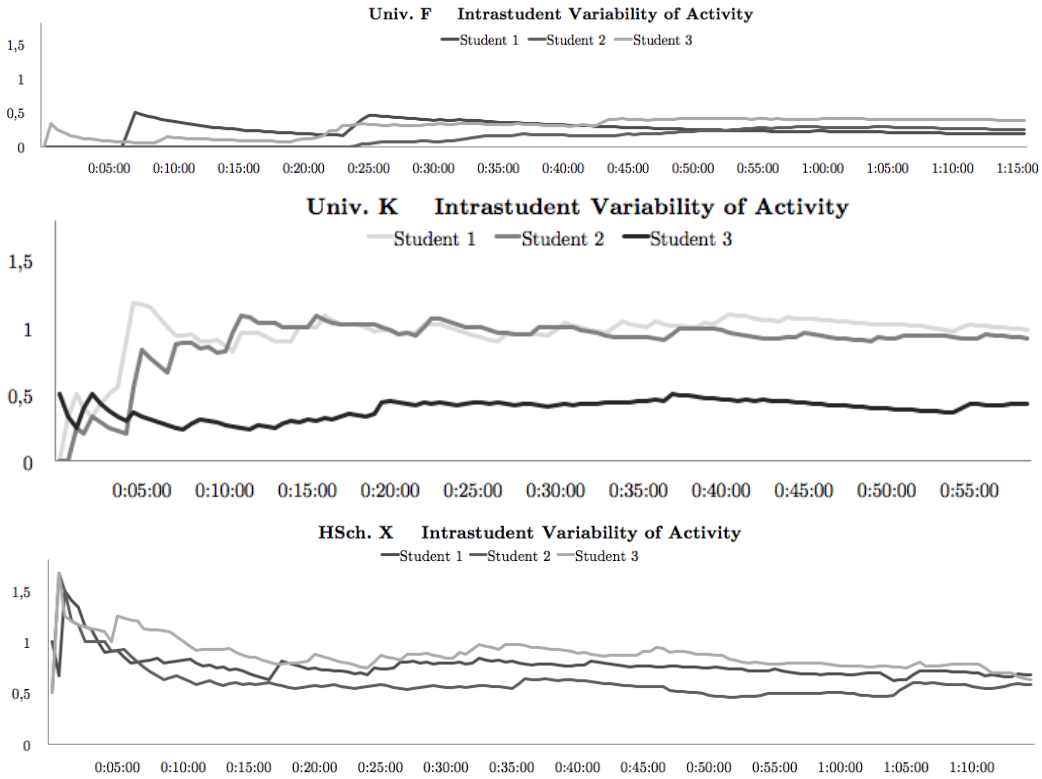


Figure 6: Chronological changes in IV values of groups

As the chronological changes of IV values show, high CPS groups appear to have been changing in unison, whereas low CPS groups show varied

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9 changes for individual students. Such unison in the chronological investiga-  
10 tion can only be achieved if students were continuing their actions for longer  
11 periods and having a similar frequency of changes. Perhaps, one potential  
12 explanation for continuing on the same action is that these students have a  
13 better sense of mutual understanding of the task/problem they are working  
14 on. When such mutual understanding does not occur among group mem-  
15 bers, their actions may vary more often as they stop and start their physical  
16 activities more frequently. The importance of mutual understanding as a di-  
17 mension of collaboration has been recognised by other researchers [1, 5, 21].  
18 Our results suggest that the intra-individual variability of students physical  
19 interactivity can be a potential indicator of CPS quality in practice-based  
20 learning activities.  
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## 25 26 **5. Discussion**

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28 In this paper, we investigate the potential of four constructs interpreted  
29 via nonverbal indexes of students physical interactivity, to identify the level  
30 of CPS in groups of students. CPS can be investigated at the individual,  
31 group, or organisational level [23]. With the intention of creating a holistic  
32 understanding of CPS, we used investigations at both individual and the  
33 group levels. We discuss and interpret the synchrony and individual ac-  
34 countability constructs through students codes at the whole group level, and  
35 investigate the equality and the intraindividual variability values through  
36 individual students mean values.  
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39 Our first research question is: What are the observable pattern differences  
40 between groups, in terms of their nonverbal indexes of physical interactiv-  
41 ity related to the synchrony, equality, individual accountability, and shared  
42 understanding aspects of CPS? In this vein, our results show that students  
43 in high CPS groups (as evaluated by expert teachers) have member stu-  
44 dents who have high and equal scores for physical interactivity and low and  
45 equal scores for intra-individual variability. Moreover, there appears to be a  
46 positive correlation between high CPS groups and students synchrony and  
47 individual accountability levels.  
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50 Related to the first research question, our second research question is:  
51 What aspects of CPS represented with nonverbal indexes of physical inter-  
52 activity, are good predictors of high CPS groups? Our results show that  
53 the concepts of synchrony, equality and intraindividual variability are good  
54 predictors of CPS quality in group work. However, individual accountability,  
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9 when measured with our coding scheme on its own in practice-based learning  
10 environments, appears to be less valuable to predict the quality of CPS.

11 The results presented in this paper are aligned with the existing research  
12 findings in the field. For instance, earlier research on peer learning shows  
13 that collaborative groups are high in equality and mutuality (Damon and  
14 Phelps, 1989), students move in unison [37, 38], they are synchronised in  
15 their gaze during collaboration [61] and they present symmetry in terms of  
16 their status and contributions [19].

17 The paper expands the knowledge in the learning sciences field by in-  
18 troducing a new methodology to interpret the key concepts of equality, in-  
19 dividual accountability and synchrony as well as bringing in the concept of  
20 intraindividual variability as a potential indicator of the quality of CPS in  
21 practice-based learning activities.

22 The effective implementation and evaluation of CPS depend on identifica-  
23 tion of the observable features and processes of CPS. As we presented in this  
24 paper, some of these can be detected via indexes of students physical interac-  
25 tions. Nonverbal indexes are particularly useful for detecting students mental  
26 states in dynamic learning environments like practice-based learning. This  
27 argument is well supported by research in social cognition which establishes  
28 that the body movements might provide an immediate understanding of men-  
29 tal states and intentions of students [25, 27]. This research stream presents  
30 evidence that bodily states including postures, gaze, movement etc. are core  
31 to social cognition and can be used to interpret mental states [7]. Here, we  
32 investigated the concepts of synchrony, individual accountability, equality,  
33 and intraindividual variability in CPS during practice-based learning. Our  
34 results show that the coding scheme we created can be used to observe and  
35 interpret these concepts in practice-based learning environments.

36 At last, we must point out the limitations of this work as well as its poten-  
37 tial benefits. The evaluation of student performance through concepts such as  
38 synchrony, individual accountability, equality and intraindividual variability  
39 is only one part of understanding how good a student (or a group of students)  
40 is at CPS. The CPS process is much more complicated than any of the ex-  
41 isting statistical measures of CPS performance, particularly when it comes  
42 to complex learning environments of practice-based learning. However, these  
43 statistical measurements can act as useful indicators of potential quality of  
44 CPS and the triangle visualisations can be used to provide valuable feedback  
45 to teachers to shape and time their interventions in classrooms. They can  
46 also be used to present students feedback on their performances so they can  
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9 serve as a basis for self-reflection. We argue that the value and accuracy of  
10 such measurements increase when they are considered together, rather than  
11 independently, to make sense of complex learning processes such as CPS.  
12 Finally, although our results are derived from a relatively small sample, the  
13 analysis is based on a large number of data and the results are promising.  
14 Our immediate future work will be directed towards further investigation of  
15 the validity and automation of this approach with larger sample sizes.  
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## 19 **6. Conclusions**

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21 In this research paper, we present four nonverbal indexes of students  
22 physical interactivity that can be used to interpret the quality of CPS in  
23 practice-based activities. Results have shown that students in high CPS  
24 groups show high levels of physical interactivity and low levels of intrain-  
25 dividual variability. Both of these indexes present smaller ranges in high  
26 collaboration groups when compared with low collaboration groups. More-  
27 over, high CPS groups appear to present high levels of synchrony values  
28 compared to low CPS groups. Our simple coding scheme of students active,  
29 semi-active and passive positions is a practical and valuable approach that  
30 can inform the design of automated analysis systems. Our coding scheme  
31 can be automated and applied to a real classroom environment by using a  
32 learning analytics system that has the potential to detect the head directions  
33 and hand position of students (using fiducial marks for instance). Hence, we  
34 expect future research to involve attempts to automate this process of coding  
35 and provide real-time feedback to students and teachers about the CPS pat-  
36 terns of students physical interactivity during their practice-based learning  
37 activities. These results have significant implications both for the design and  
38 implementation of CPS activities in classrooms and they would increase the  
39 accuracy and timeliness of teacher interventions.  
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46 We argue that CPS has potential to prepare students for the future of  
47 democratic societies in which the humans mostly deal with ill-defined, open-  
48 ended tasks whereas the most well-defined tasks are dealt with automated  
49 agents. Education has utmost significance to provide the required training of  
50 students in CPS. In this paper, we provide a contribution to this big picture  
51 with some statistical analysis of students nonverbal indexes of their physical  
52 interactivity. However, we want to note that the most effective and efficient  
53 education can only be provided through combining such measurements of  
54 student performances with teachers expert instinctive judgment of the learn-  
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9 ing situations. Nevertheless, it would be a mistake to rely only on instinctive  
10 judgment, in the same way, that it would be a mistake to rely only on sta-  
11 tistical calculations of certain proxies of complex learning processes such as  
12 CPS. The measures proposed here are aimed to empower teachers with in-  
13 formation that they can use to obtain a better view of the whole picture so  
14 that they can plan and adapt instruction accordingly.  
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## 17 18 **7. Acknowledgments**

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## Highlights: The NISPI framework: Analysing collaborative problem-solving from students' physical interactions

- A framework to interpret collaborative problem-solving from nonverbal indexes of physical interactivity is proposed.
- Synchrony, equality, individual accountability, and intra-individual variability are key parameters of CPS.
- High competency groups show high levels of physical interactivity and low levels of intra-individual variability.
- Both of these parameters present smaller variability in high competency groups.
- High competency groups present high levels of synchrony in their behaviours.

