Utilising technology in the assessment of collaboration: A critique of PISA's collaborative problem-solving tasks

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Introduction

Technological tools are increasingly becoming embedded in learning, teaching, and assessment. Advances in technology offer new opportunities for assessing collaborative learning and problem-solving in areas and contexts where assessment would otherwise not be possible. Technology can support facilitation and assessment of group collaborative learning in three ways: as a facilitator of interaction (Kreijins, Kirschner, Jochems, & Van Buuren, 2004), as a record keeper (MacDonald, 2003), or as a collaborative partner (Rosen & Tager, 2013). In this article, we briefly introduce each of these areas, before presenting an analysis of how these approaches have been enacted in relation to the Programme for International Student Assessment (PISA).

Technology as facilitator

A key issue when introducing some forms of technology relates to the concept of the 'virtual team'. Virtual teams have been described as comprising members who are geographically dispersed, but who use computer-mediated communication tools to coordinate their individual contributions (Peters & Manz, 2007). Peters and Manz (2007) argue that the higher the levels of trust between members of a virtual team, the higher the collaboration levels. This is an important consideration as members of a virtual team ordinarily have very limited face-to-face opportunities for communication in order to establish relationships. In essence, face-to-face meetings afford opportunities for members of a group to know more about each other (Mortensen & O'Leary, 2012). Unfortunately, trust takes time to grow (Henttonen & Blomqvist, 2005) and thus the role of trust in virtual teams assumes great importance (Jarvenpaa, Knoll & Leidner, 1998; Horwitz, Bravington & Silvis, 2006).

Technology as record keeper

Computer-mediated communication environments can also provide a record of activity that can be kept, replayed, and modified. The use of technology can facilitate the capturing of student activity, from which individual contributions to the collaborative process can be judged. Technology can be effectively used to provide evidence of 'artefacts' generated in the collaborative interaction in some cases, for example, by observing students as they progress on a task with a video capture software (Siemon & Scholkmann, 2015). Other examples include log files (Adejumo, Duimering, & Zhong, 2008) and capturing collaborative communication (Foltz & Martin, 2008).

Technology as collaborative partner

A challenge for assessors of collaboration is to ensure that the assessment approach can accurately capture and assess group activity and the *individual* contributions to the collaborative effort (Rosen & Foltz, 2014). Typically, the emphasis of assessment is usually at the level of individual students. This poses a challenge for the appropriate assessment of collaboration, because it is difficult to pinpoint individuals' contributions to the group effort, and to isolate these contributions from the 'noise' created by different group compositions. For example, collaborative tasks can instil conditions that encourage undesirable effects including 'social loafing' (Petty, Harkings, Williams & Latane, 1977), 'free riding' (Delton, Cosmides, Guemo, Robertson & Tooby, 2012), and competition between group members. There is also the possibility that group activities encourage a lack of different viewpoints in some cases, when group cohesion is valued over final outcomes (Rimor, Rosen & Naser, 2010).

One method of instilling a degree of standardisation in the assessment of collaboration is to utilise computer-simulated collaborative partners. The computer agent initiates collaborative behaviour, but occasionally 'tests' the test-taker by displaying some misunderstandings, or by suggesting misleading strategies. The test-taker at this point must negotiate and resolve the conflict with the computer.

Aims of the present research

There is an increasing interest in understanding how collaboration is fostered and subsequently assessed. Lee and Bonk (2014, p.10) argued that "collaborative processes and activities, as well as the technological tools for enhancing teamwork, have become increasingly critical to workplace success". The technological advancements described above, and the emerging 'assessment imperative' for so-called twenty-first century skills (Stahl, 2015) led the Organisation for Economic Cooperation and Development (OECD) to develop an assessment framework for collaboration that utilised a technological solution, which was used in PISA 2015. Each student participated in tasks where they collaborated with computer-based conversational agents only. These agents were designed to represent group members who exemplified a range of collaborative skills, knowledge, and understanding, and were programmed to introduce a degree of conflict that needed to be negotiated by the individual student. Technology was used in an attempt to control interactional boundaries, with the intention of pinpointing collaborative behaviours and traits in individual students' responses and recording them.

Our article presents the outcomes of an exercise which we conducted to map the assessment approach of PISA 2015 to pertinent facets of the collaborative process, and recent theoretical developments related to engenderment of collaboration within assessment tasks. PISA's assessment of collaborative problem-solving was mapped onto six facets of collaboration identified in a recent review of the literature (Child & Shaw, 2016, see Figure 1 for an overview) and five elements of task design that were identified in our previous review as contributing to the optimal engenderment of collaborative activity. Our present article's mapping approach afforded the opportunity to investigate in detail the advantages and disadvantages of PISA's approach to the use of technology in its assessment of collaboration.

PISA's assessment of collaborative problem-solving using technology

The development of the PISA collaborative problem-solving assessment was built on the problem-solving framework for PISA 2012 (OECD, 2013). The OECD extended this framework to incorporate the additional concepts that focus on the collaborative aspects of problem-solving.

There are three collaborative problem-solving competencies identified in the OECD's collaborative problem-solving framework, each with a weighting:

1. Establishing and maintaining shared understanding (40–50%);
2. Taking appropriate action to solve a problem (15–30%); and
3. Establishing and maintaining group organisation (30–35%).

These competencies are synthesised with problem-solving competencies identified in PISA 2012: exploring and understanding; representing and formulating; planning and executing; and monitoring and reflecting. This synthesis is represented by a matrix of collaborative problem-solving competencies, to which specific items are designed to relate (Table 1).

Table 1: Matrix of collaborative problem-solving competencies (from OECD, 2013)

	(1) Establishing and maintaining shared understanding	*(2) Taking appropriate action to solve a problem*	*(3) Establishing and maintaining team organisation*
(A) Exploring and understanding	A1: Discovering perspectives and abilities of other team members.	A2: Discovering the type of collaborative interaction to solve the problem along with goals.	A3: Understanding roles to solve problem.
(B) Representing and formulating	B1: Building a shared representation and negotiating the meaning of a problem (common ground).	B2: Identifying and describing tasks to be completed.	B3: Describe roles and team organisation (communication protocol/rules of engagement).
(C) Planning and executing	C1: Communicating with team members about the actions to be/being performed.	C2: Enacting plans.	C3: Following rules of engagement (e.g., prompting team members to perform their tasks).
(D) Monitoring and reflecting	D1: Monitor and repair the shared understanding.	D2: Monitoring results of actions and evaluating success in solving the problem.	D3: Monitoring, providing feedback and adapting the team organisation and goals.

Part of the criteria for PISA's collaborative problem-solving construct was taking appropriate actions, using the information gathered from a previous response and an evaluation of its success (part D of the matrix). This part of the criteria was given a lower status in comparison to maintenance of the collaborative state and team organisation. The focus of PISA's 2015 assessment of collaboration was aspects of team organisation (understanding of roles within a group).

Collaborative problem-solving assessment description

The PISA assessment tasks developed to align with the OECD's collaborative problem-solving framework involved an individual student collaborating with computer-based partners, as part of a simulation of real-world collaborative activity. Each student participated in collaborative problem-solving scenarios which lasted between 5 and 20 minutes each. Within each scenario, there were several chat-based tasks where each student interacted with one or more simulated group members to solve the problem presented in the scenario. The simulated group members represented different knowledge sets and ability ranges.

There were three different task types that could reside within the overall scenarios (OECD, 2013):

1. **Consensus building:** A task type where the group needed to make a decision after considering the views, opinions, and arguments of different members.
2. **Jigsaw problems:** Each simulated group member in the task was provided with different information. The individual student had to recruit the simulated group members to pool their information and skills to achieve the group goal.
3. **Negotiations:** Group members had different amounts of information and different personal goals. Through negotiation, each student was tasked with selecting information that could be passed on so that there could be mutual win-win optimisation which satisfied overall group goals.

The assessment structure attempted to cover the 12 cells of the matrix described in Table 1, and according to the given weightings. Each item score contained within the simulation contributed to the score for only one cell of the matrix. For example, some items emphasised exploring common ground (A1), others the clarification of roles (B2), enacting plans (C2), or reflection on the successes and issues of the interaction (D3). Full-credit responses were those that targeted the maintenance of the collaborative state (Brna, 1998), whether this was achieved through refocusing on the task, offering a solution, or assigning task roles.

Construct mapping framework

Child and Shaw (2016) identified six facets related to the collaborative process (Figure 1) and suggested five prerequisites related to assessment task design and group dynamics from which collaboration can be optimally engendered. These five prerequisites are related either to the task itself or to aspects of group composition:

1. **Task should be sufficiently complex:** the problem should instil a discussion and negotiation within the group about the best course of action.
2. **Task should be ill-structured:** the task should be designed so that the appropriate course of action is not immediately outlined or discoverable.
3. **Task should only utilise non-superfluous technologies:** the task should only use technology that is essential in allowing collaboration to take place, and does not create barriers to interaction.

Social interdependence

When the outcome of individuals is affected by their own and others' actions. Positive interdependence is when individuals believe that they can achieve their goals if other individuals achieve their goals as well. Negative interdependence (or competition) is when individuals believe they can only achieve their goals if others fail. Implies a degree of synchronicity between group members, in that they are compelled to work together, and are thus motivated to do so (Johnson, Johnson & Smith, 2007).

Conflict resolution

Peer interaction promotes cognitive conflict by exposing discrepancies between peers' own and others' knowledge. The negotiation of conflicts of viewpoint is an important aspect of effective collaborative task design (Fawcett & Garton, 2005; Rosen, 2014).

Introduction of new ideas

Related to conflict resolution, team members should be effective in offering solutions for the task at hand, which can then be negotiated (OECD, 2013).

Sharing of resources

Part of the maintenance of the collaborative state. An effectively designed collaborative task should not be able to be solved by individual effort. Subsequently, resources should need to be pooled amongst team members (Brna, 1998).

Cooperation/task division

Cooperation is a division of labour between group members. It occurs when a task is divided up into individually manageable subparts, which are subsequently constructed into a final outcome. Although this is conceptually different to collaboration, at a fine-grained level, all collaborative tasks have a degree of cooperation (Lai & Viering, 2012).

Communication

Communication in a collaborative task comprises rich interactive features, of which only one is the speech (or text) produced by group members. During the collaborative task, communication acts to bring implicit thought to explicit explanation (Webb, 1991).

Figure 1: The six facets of the collaborative process (from Child & Shaw, 2016)

4. **Group member dynamics should engender negotiation:** students should be in groups where there may be differences in opinion.
5. **Group is motivated to work together:** the assessment is designed to motivate group members to work together.

The six facets of the collaborative process and the five task prerequisites were then mapped onto the example tasks of the draft collaborative problem-solving framework (OECD, 2013, 2015) described above. This helped identify which facets of collaboration were targeted within PISA 2015, and to what extent. The outcomes from the mapping exercise are outlined in Tables 2 and 3 and summarised in the following section.

Summary of mapping outcomes

The mapping exercise found that PISA 2015's tasks instilled interdependence, as the synthesis of knowledge from different group members was required for successful completion. It is questionable, however, as to whether this interdependence is 'social', because the outcome of the task is of no consequence to the computer. Johnson and Johnson (1989, 2002) argued that social interdependence is achieved when the outcome of individuals is affected by their own and others' actions, and that there is a shared overall outcome. The simulations underpinning the task in PISA 2015 mean that students cannot share an outcome with the other members of the group. However, Rosen and Foltz (2014) suggested that competitiveness may be an issue within human-to-human collaborative tasks, and thus the lack of this aspect as part of a human-computer interaction within PISA 2015 may actually improve the 'quality' of the endeavour. Furthermore, little time is needed to find common ground, which has been identified as being an important precursor to coordinate joint understandings of tasks (Clark, 1996).

Mapping also found that individual students had to share resources amongst their simulated group members to perform tasks effectively. For example, the jigsaw task was designed so that resources needed to be shared amongst group members for the task to be completed. A student was rewarded if they were able to actively share the information amongst the simulated group members and synthesise it.

One of the five prerequisite task criteria for a collaborative task was that group member dynamics should engender negotiation. In a standardised assessment of an individual student's collaboration, each student should be matched with various types of group members that will represent different collaborative skills and contexts, thus instilling discussion, negotiation, and resolution. The complexity and ill-structured nature of a task, and elements of individuals within the group, interact to afford the possibility of 'true' collaboration. The mapping for this article found that this criterion is largely met by PISA 2015. Each of the computer-based collaborative agents had their own distinct personality 'traits' which individual students had to manage and negotiate with to optimise outcomes. These were enacted periodically to test the student on particular aspects of the collaborative process.

PISA's approach to assessing collaborative problem-solving was that each set of item responses was situated within a context from which a judgement could be made about which response is optimal. For example, if an item had four potential set responses, PISA identified which response was best, relative to the other responses. There may also be a second response that received partial credit. The 'messenger' format of the interactions between the student and the computer-based collaborative partners allowed significant control in the range of situations, conflicts, and points of negotiation to which each student was exposed. In this sense, the discourse between group members was controlled to the extent that it allowed individual students to be compared on similar experiences and situations (Rosen & Tager, 2013). This approach has implications for one of the five prerequisites for a collaborative task – that the task should be ill-structured. The range of responses available to the student for each item (typically four) did not represent the full range of responses that would be possible in a real-

Table 2: Mapping of Child and Shaw's (2016) facets of collaboration to PISA 2015

Collaboration as process		
Six facets of the collaborative process (From Child & Shaw, 2016)	*Evidence from Collaborative problem-solving framework (OECD, 2013) and example tasks (OECD, 2015). Direct quotations are in italics.*	*Comment on sub-construct alignment*
1. Social interdependence	OECD (2013) states that *"Assessment items will be designed so that successful performance on the task requires collaboration and interdependency between the participants"* (p.15). This claim is supported by the 'jigsaw problem' task. It is built into the task that each group member had different information or skills. Each student needed to pool the information and recruit the skills and information from other collaborators in order to achieve the group goal. OECD (2013) states in the 'establishing and maintaining group organisation' descriptor (p.29) that *"Student acknowledges, inquires, assigns, or confirms roles taken by other group members and resources needed by other group members"*. However, the 'negotiation' task implied that group members have different personal goals. This could potentially encourage some negative social interdependence if this task was misconstrued.	There are elements of both the tasks themselves and the proficiency descriptors that suggest that social interdependence was the focus of the OECD's collaborative problem-solving framework. Social interdependence is to some extent dependent on a shared outcome (Bossert, 1988), which in assessment is indicated by shared marks. This is not possible in human-computer interactions.
2. Conflict resolution	If a student attempted to move to a solution too quickly, the computer agents offer new opinions and options which required consideration and negotiation by the student.	Many of the conflicts are *implicitly* assessed. For example, there were instances where a difference of opinion or lack of focus is introduced by the computer-based partner, which the student has to negotiate.
3. Introduction of new ideas	The 'taking appropriate action' descriptor (p.29) states that *"Student takes the initiative to identify, propose, describe, or change the tasks when there are changes in the problem or when there are obstacles towards the solution"*.	As each item has four response options, the student was not responsible for the creation of new ideas, but understanding when a new idea (as expressed by the response options) should be introduced into the interaction.
4. Sharing of resources	The 'establishing and maintaining shared understanding' descriptor (p.29) states that *"Student actively shares information and perspectives about self and others when it is needed"*. The 'jigsaw problem' task ensured that the student and the computer-based collaborative partner/s have resources (information) that would be useful for the student to synthesise in moving towards an optimal solution.	Sharing of resources was built into both the tasks and the descriptions of performance.
5. Cooperation/ task division	Cooperativeness of group members is identified as part of 'establishing and maintaining team organisation' (p.29). The 'establishing and maintaining team organisation' level descriptor (p.29) states that *"Student's actions and communications show taking the initiative to understand and plan the different group roles that need to be taken to solve the problem."*	In the example tasks, cooperation was closely aligned with the idea of maintaining team organisation. The 'planning of group roles' may or may not involve cooperation (i.e., division of labour). .
6. Communication	Students must communicate to collaborate in the tasks. The communication stream was captured and analysed to measure the underlying processes. The 'taking appropriate action to solve the problem' descriptor (p.29) states that *"Student inquires about the actions, tasks, and plans to be completed by members of the group to solve the problem when contextually appropriate."* Students had to respond to text-based communication from computer-based collaborative partners. They had to choose from four options by clicking on the screen.	Although the scenarios were framed in a messenger-type scenario, the responses were not genuinely 'chat-like' and therefore potentially limiting. The tasks did not allow spontaneous responses. The response options offered did not reflect the full range of possible responses to each item within the scenario/s.

world context. Furthermore, it is unclear as to whether the responses available to the student were optimal, both relative to other responses, and to the infinite potential responses in the natural world. The optimum outcomes were pre-defined by the task-setter, and had in-built structure. Therefore, the degree of ill-structure might not be representative of what occurs in natural collaborative activity.

In PISA 2015, the use of computer agents meant that students had to respond to items using pre-designed textual responses. This was so that the computer agents could 'understand' the input from the student. This limited the use of other communicative strategies (for example, gestural communication) that students would potentially utilise in a human-to-human collaborative interaction, as well as the potential to share resources and introduce new ideas. Research has found that collaborators change their communication depending on their knowledge about the other communicative partners. For example, when participants were told they were interacting with a computer agent, they provided fewer references to emotion and affiliation with their partner, even when they were actually collaborating with another human (Hiyashi & Miwa, 2009). This suggests that the preconceptions that human group members had developed, based on the information that they had received previous to the commencement of the interaction, significantly influenced how they collaborated in the task.

Finally, the nature of the assessment also raises the possibility that students could be motivated to respond differently in the PISA

Table 3: Mapping of Child and Shaw's (2016) task prerequisites for collaboration to PISA 2015

Task prerequisites (From Child & Shaw, 2016)	*Evidence from PISA 2015*	*Comment on task-setting criteria alignment*
1. Task should be sufficiently complex	The collaborative task was closely tied to the concept of a 'problem'. OECD (2013) defined a problem (p.9) as existing *'when a person has a goal but does not have an immediate solution on how to achieve it'. That is, 'problem solving is the cognitive processing directed at transforming a given situation into a goal situation when no obvious method of solution is available'.*	The solutions for the tasks were unlikely to be appropriately solved by an individual student, and therefore are sufficiently complex.
2. Task should be ill-structured	Implicit in the assessment was the idea of an optimal solution/path towards a pre-defined end goal. This was a structured aspect of the assessment, as there is a final target solution that was decided by the task-setter. This goes against the conventional wisdom that task solutions should be open-ended and ill-structured.	The task was designed to have the 'appearance' of ill-structure. The student had no concept of the optimal outcome at task onset.
3. Task should only utilise non-superfluous technologies	Measurement was operationalised using computer-based agents as a means to assess collaborative skills. Students collaborated with computer-based conversational agents that represented team members with a range of skills and abilities.	The use of technology in this approach allowed a high degree of control and standardisation required for measurement.
4. Group member dynamics should engender negotiation	The group composition was determined by the task. In the examples given, there were up to two computer-based partners, each with their own characteristics. For example, one of the computer-based group members would stray off topic, and the student had to respond appropriately to keep the interaction focused.	The requirement for negotiation was built into the tasks.
5. Group is motivated to work together	Students were aware of the computer-based nature of the task, which might have affected participant motivation.	It is unclear as to how students responded to the computer-based collaborative task in terms of motivation. Motivation might be individualistic rather than shared.

collaborative tasks compared to how they would in real-life settings. This is a potential issue for one of the five task criteria – that the group is motivated to work together. Stahl (2015) suggested that the values of the collaborative framework that PISA utilised are apparent within the item choices. If this is the case, there is a potential mismatch between how a student would respond in a natural setting and how they believe they should do so to score well in the assessment. It is reasonable to assume that students were aware of the aim of the PISA assessment and the emphasis on being seen to collaborate. Whilst this issue is not unique to computer-based collaborative tasks, it does raise the question of authenticity and whether true social interdependence is possible in these tasks (Johnson & Johnson, 2002) and thus whether the individual students in PISA 2015 were motivated by different concerns compared to how they would be in a natural setting.

Conclusions and future directions

The ambition to introduce technology into the assessment of an individual's collaboration can be achieved in several ways. The challenge for assessment developers is to reconcile this ambition with considerations related to the target construct. Our article provides an analysis of the alignment of the OECD's approach to the assessment of collaboration using a previously developed theoretical framework.

PISA's assessment of collaborative problem-solving is a thorough attempt at enacting the construct of the process of collaboration, whilst using technology to provide a degree of standardisation so that comparable judgements on individual student performance can be made. Computer-based methods for the measurement of the construct of collaboration have some advantages for assessors. For example, the task can be standardised, which can facilitate the development of scoring rubrics. Furthermore, computer-based assessment can standardise aspects of interactions to facilitate the judgement of individual students. Computer-based assessment offers a 'simulation' of a collaborative task within controlled parameters. The mapping conducted in this article suggests that this approach as a means to enable 'true' collaboration, as we conceptualise it, is open to question. To illustrate this point Krkovic, Pásztor-Kovács, Gyöngyvér and Greiff (2013, p.3) suggested that "a compromise must be made and scientists have to decide if the high standardization that computers offer is worth sacrificing the face validity that human-based collaboration offers".

Our critique of PISA could lead to future work that analyses the elements of the process of collaboration that have been targeted effectively, and areas for future improvement. Specifically, it is yet to be confirmed whether a fundamental technological aspect of the assessment (the use of computer-based partners) introduces any limiting factors to the interaction. This research could provide important insights into how technology can be best utilised in the development of models of assessment for collaboration. This will be of interest to awarding organisations and others that are looking to develop qualifications in this important twenty-first century skill.

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