Master's Thesis

The effect of transactive dialogue prompting in a collaborative serious game in secondary education

Kevin J. Hartery
S2860767

University of Twente
Faculty of Behavioural, Management and Social Sciences
MSc Educational Science and Technology

First supervisor: Dr. Judith ter Vrugte
Second supervisor: Dr. Hannie Gijlers

July 2023

Foreword

I would like to express my sincere gratitude to the individuals who have supported me throughout this research endeavour. First and foremost, I would like to extend my appreciation to my supervisor, Dr. Judith ter Vrugte, for her guidance and support throughout the entire research process. I am also grateful to my second supervisor, Dr. Hannie Gijlers, for her insightful feedback and constructive suggestions that greatly contributed to the refinement of this study. I would also like to thank Dr. Alejandro Catala Bolos, who dedicated a lot of hours in ensuring that the app was functional and holding my hand in adapting it for this project. Additionally, I would like to thank Else and Monique, for their friendship and guidance. Finally, I would like to thank my parents, my brothers, and especially my girlfriend, Aislin (who will be very relieved that I am graduating), for supporting me every step of the way. Without them this study would not have been possible. Bedankt and go raibh míle maith agaibh.

Abstract

In science, technology, engineering and mathematics education, students often struggle to obtain deep conceptual understanding of learning material. Collaborative serious games provide opportunities for deep learning as they can encourage students to discuss, critique, and integrate explanations offered by their peers. When students do this, they are engaged in transactive dialogue. However, without support, students often do not engage in transactive dialogue which can threaten the learning outcomes of collaborative serious games. Prompting can be used to encourage students to offer explanations to the group, providing a basis for transactive dialogue. As such, this study aimed to investigate the effect of transactive dialogue prompting on the effectiveness of a collaborative serious game. A tablet-based game training proportional reasoning was used in a small group setting in a first-year group, aged 11 to 13 ($M = 13.05$, $SD = 0.366$), at a secondary school in Ireland. The sample included 84 first-year secondary school students ($N_{male} = 38$ and $N_{\text{female}} = 46$), who were divided into groups of four to play the game. These groups were randomly assigned to either the experimental ($n = 11$) or control ($n = 10$) conditions. The experimental group played the game with the inclusion of transactive dialogue prompts, and the control group played the game without prompts. Students completed knowledge tests before and after the intervention to measure their knowledge gain. The discussions of the groups were recorded and coded for the occurrence of transactive dialogue. Both learning and transactive dialogue did occur during the game, but the results found no effect for prompting on the level of transactive dialogue or learning. However, students in the experimental condition did make less incorrect moves during the game, suggesting that students may have thought more deeply about their actions. As such, transactive dialogue prompting may be of educational benefit. Future studies should examine transactive dialogue prompting and incorrect moves to understand the reasons for any relationship. This may further increase our understanding and help to advance the design of such support in collaborative serious games.

Keywords: transactive dialogue, prompting, collaborative learning, serious games, collaborative games, computer-supported collaborative learning (CSCL)

Problem Statement

Using collaborative serious games (CSGs) in schools could benefit learners in science, technology, engineering, and mathematics (STEM) subjects where students often struggle with gaining deep conceptual understanding through traditional instructional methods (de Jong, 2019; Freeman et al., 2014). Serious games provide an opportunity to promote deep conceptual understanding of learning material because they are highly motivating for students and are often played repeatedly (Tobias et al., 2014). Furthermore, game-based learning has been demonstrated to have favourable learning outcomes over conventional instruction for mathematics (Hays, 2005). The effectiveness of serious games as an educational tool can be increased when combined with collaborative learning (Inkpen et al., 1995, van der Meij et al., 2019). Collaborative learning has been linked with lowering demands on cognitive capacity (Kirschner et al., 2014), helping with the development of metacognitive strategies (Wismath & Orr, 2015), and fostering generative processing (Kirschner et al., 2014). Collaborative games promote learning by encouraging learners to engage in dialogue about the game (van der Meij et al. 2019).

However, not all forms of collaborative dialogue result in increased learning outcomes (Teasley, 1997; van der Meij et al., 2019; Weinberger & Fischer, 2006). Research shows that dialogue during serious games often focuses on superficial game elements, rather than meaningful discussions pertaining to the core educational material presented by the game (Dillenbourg, 2002; van der Meij et al., 2019; Wouters & Oosterdorp, 2013). Effective collaborative learning involves transactive dialogue, which occurs when learners engage with information offered by fellow group members (Slavin, 2014; Teasley, 1997). When learners communicate transactively, they can generatively process the learning material by sharing, comparing, and repairing their respective mental models (Barron, 2003). Moreover, an absence of transactive dialogue during collaborative learning threatens the construction of conceptual understanding (Kirschner et al., 2014; van der Meij et al., 2019). Learner support is required to direct group dialogue towards transactivity (Dillenbourg, 2002).

Prompting is a learner support that is used when learners are believed to possess the ability to perform a task but are not expected to perform it independently (de Jong & Lazonder, 2014). More research is needed to see if prompting learners to engage in effective collaboration could precipitate meaningful, domain-related discussions, thus increasing the efficacy of serious games for learning. As such, this paper investigates the effect of transactive dialogue prompts on the effectiveness of a collaborative serious game. In addition, it examines the effect of the prompt on the level of transactive dialogue during gameplay, and whether an increase in transactive dialogue can be linked to an increase in knowledge gain.

Theoretical Framework

Collaborative Serious Games (CSGs)

Serious games are often described as games with a deliberate educational basis (Abt, 1970) and a primary purpose other than fun or entertainment (Abt, 1970; Darwesh, 2016; Susi et al., 2007). The word 'serious' is used to convey the deliberate design of the game to impart learning (Abt, 1970; Laamarti, 2014). Serious games can be played digitally, with the addition of digital technology providing a rich multimedia experience including text, animations, and audio (Laamarti, 2014; Tobias et al., 2014). Digital games offer opportunities for learning because they can be highly motivating and are often played repeatedly by players (Tobias et al., 2014).

Existing research shows significant increases in knowledge gain for students playing games versus traditional instruction (Clark et al., 2016; Vogel et al., 2006), particularly in mathematics education (Hays, 2005; Pareto et al., 2014). There are, however, concerns that their efficacy is constrained to certain use cases only (ter Vrugte, 2016), and that they can fail to meet their educational objectives without adequate support (van der Meij et al., 2019).

Games require supplementary learner support to be effective learning tools (Leemkuil & de Jong, 2012; van der Meij et al., 2019; Wouters & van Oostendorp, 2013). Playing a game can require a large cognitive load (Tobias et al., 2014). Learner support can reduce extraneous cognitive processing by directing a learner's attention towards the educational goal of the game (Wouters & van Oosterdorp, 2013). Collaborative learning can be used as a learner support by facilitating learners to pool their cognitive resources to accomplish a cognitively demanding task (Kirschner et al., 2014), and through learners benefitting from explanations provided by their collaborative partners (ter Vrugte et al., 2015; Weinberger & Fischer, 2006).

Collaborative learning involves groups of two or more learners combining to carry out a shared learning objective (Cooney & Darcy, 2020; Laal & Laal, 2012; van der Meij et al., 2011). Successful collaborative learning involves listening to the ideas of others and communicating and justifying one's own ideas (Laal & Laal, 2012; Teasley, 1997). This facilitates learners to generate their own mental models of the learning material, rather than depending on the understanding provided by a teacher (Kirschner et al., 2014). From the perspective of cognitive learning theory, collaborative learning allows learners to utilise each other's cognitive processing, increasing the pool of information processing available to group members (Kirschner et al., 2014). It follows that CSGs involve multiple learners collaboratively playing a serious game.

The potential educational benefits of CSGs are best noted when compared to traditional classroom instruction (Kirschner et al., 2014; Pareto et al., 2014), or versus solo play of serious games (van der Meij et al., 2011). In a study conducted by Inkpen et al. (1995) participants played a serious game. The study involved three different conditions: solitary play, parallel play, and collaborative play. The results revealed that collaborative play yielded significantly higher scores in terms of learning outcomes compared to the other modes of play. The authors speculated that these positive outcomes were a direct result of the verbal interactions between the players during collaboration. They proposed that players engaged in discussions about the game, articulating their moves, exchanging ideas, and presenting arguments. Ter Vrugte et al. (2015) utilised collaborative learning in a serious game as a learning support in a study among Dutch pre-vocational students. The study found evidence that serious games can improve learning outcomes for mathematics education, but that the competitive aspect of the game negated the benefits of collaborative learning (ter Vrugte et al., 2015).

The effect of group dialogue during collaborative learning has been widely acknowledged as a key advantage over solitary work in educational studies (Barron, 2003; Dillenbourg, 2002; Teasley, 1997; van der Meij et al., 2011; Weinberger & Fischer, 2006). However, it is important to recognise that not all verbal interactions contribute equally to the development of knowledge (Teasley, 1997; van der Meij et al., 2019; Weinberger & Fischer, 2006). It is thus important to investigate the type of dialogue that contributes to learning outcomes from collaborative learning.

Transactive Dialogue

Collaborative learning requires a range of dialogue which can be off-task or on-task (Weinberger & Fischer, 2006). Before learning can even begin, collaborative learners must often invest additional cognitive resources in off-task dialogue, to create a group identity (Kirschner et al., 2014) or by encouraging other group members to participate in the activity (Barron, 2003). Collaborative learning also involves on-task dialogue, which relates to the educational material of the learning task (van der Meij et al., 2019; Weinberger & Fischer, 2006). On-task and off-task dialogue are both part of the intricate process of collaborative learning, contributing to group performance and interacting with each other in varying ways (Barron, 2003). Nevertheless, on-task dialogue is of more interest to researchers (van der Meij et al., 2019) because it has been positively associated with learning outcomes (Cohen, 1994).

More recent research on collaborative learning points to a confounding component of on-task dialogue, known as transactivity, for this knowledge gain (Teasley, 1997; Weinberger & Fischer, 2006).

Increased learning outcomes result from group dialogue which is transactive (Teasley, 1997; Weinberger & Fischer, 2006). Transactive dialogue occurs when learning partners engage with the contribution of ideas by others to the group discussion (Teasley, 1997). When learners share their ideas with the group, a shared mental model is formed (Kirschner et al., 2014). This process illuminates differences between an individual's understanding and other group members' understanding of the learning material (Kirschner et al., 2014; Piaget, 1965; Teasley, 1997). Discussing these differences leads to increased learning as learners share, compare, and repair their own understanding (Barron, 2003) and subsequently progress the shared mental model of the group (Kirschner et al., 2014). Previous research has identified transactive dialogue by analysing collaborative group discussions.

Weinberger and Fischer (2006) provide a framework for transactive dialogue. They provide five categories of dialogue in increasing levels of transactivity, based on the work of Teasley (1997). *Externalisation* is when a learner contributes to the discussion by providing their view. *Elicitation* is when a learner asks for information from a learning partner. *Quick consensus building* is when learners reach an agreement to expedite the learning task and not necessarily because they are convinced by the argument of their groupmate. *Integration-oriented consensus building* occurs when learners act upon the input of learning partners, often by changing their own view based on the input. *Conflict-oriented consensus building* is when learners disagree with, modify, or provide alternative viewpoints to the input of other group members. Researchers have noted that the higher levels of transactive dialogue are better correlated with learning (Teasley, 1997; Weinberger & Fischer, 2006). This is because higher levels of transactive dialogue only occur when learners interact with the ideas of their group members (Teasley, 1997), facilitating learners to benefit from each other's input (ter Vrugte et al., 2015; Weinberger et al., 2010), while advancing the shared understanding of the learning material (Kirschner et al., 2014). Transactive dialogue is a topic of interest in many types of collaborative learning activities, however, CSGs possess their own challenges in encouraging transactivity.

The content of dialogue which occurs during collaborative gameplay often focuses on superficial game elements, which does not result in increased learning (Dillenbourg, 2002; van der Meij et al., 2019; Wouters & Oosterdorp, 2013). In a study by van der Meij et al. (2011), most of the collaborative dialogue of the groups revolved around superficial game elements, for example, describing the game interface. Collaborative dialogue requires the transactive exchange of ideas related to the educational goals of the game to result in knowledge gain (Weinberger & Fischer, 2006). A popular approach to increasing the educational productivity of group dialogue is through providing learner support (Barron, 2003; Dillenbourg, 2002; van der Meij et al., 2019).

Supporting Transactive Dialogue

Serious games often include additional game elements, such as rules, characters, graphics and learner supports to supplement the learning experience (Tobias et al., 2014). Learner support is regarded as a necessary component of serious games for learning to occur (Leemkuil & de Jong, 2012). In the case of collaborative learning, the group discussion should have a degree of structure for it to be fruitful (Dillenbourg, 2002). Learners need to be directed towards the learning material of the game and encouraged to engage with it (van der Meij et al., 2019).

Previous studies have looked at implementing learner support to increase the occurrence of transactive dialogue in collaborative games (van der Meij et al., 2019; Weinberger & Fischer, 2006). Scripting is one mechanism for encouraging transactive dialogue that is used (van der Meij et al., 2019; Weinberger & Fischer, 2006; Weinberger et al., 2010). Scripted collaboration involves interrupting the innate discussion of the group, directing dialogue instead towards the instructional material (van der Meij et al., 2019). A study by van der Meij et al. (2019) investigated the effect of scripting on collaborative dialogue, motivation, and learning outcomes in a serious game. The study reported a significant effect of scripting on the amount of high-level transactive dialogue, as well as on learning outcomes.

While learning outcomes did increase in the study of van der Meij et al. (2019), Dillenbourg (2002) warns that the dialogue of scripted collaborative groups can seem productive without truly activating the learning mechanisms of collaboration. This can occur if the discourse is overly scaffolded; for example, if learners are given sentence starters, it may indeed appear to lead to an increase in the occurrence of transactive dialogue, but without necessarily triggering the processes of collaborative learning which foster meaningful learning for participants (Dillenbourg, 2002). In addition, when confronted with a complicated learning environment, learners can become overloaded and hold back from pursuing tasks which further their learning (Wouters & van Oostendorp, 2013). Furthermore, overly structured supports for collaborative dialogue can discourage learners from pursuing their learning goals (Weinberger et al., 2005). Prompting is seen as a less intrusive form of learner support (de Jong & Lazonder, 2014). When learners are believed to possess the ability to perform a learning process, but are not expected to do so independently, prompting is used as a reminder (de Jong & Lazonder, 2014).

A prompt could remind a learner to externalise their thoughts with other group members, kickstarting transactive dialogue in the group by providing a basis for knowledge co-construction. The process through which learners externalise their thinking to themselves or others is called self-explanation (Wylie & Chi, 2014). Learner self-explanations mirror the transactive dialogue process of externalisation, as discussed earlier, from Weinberger and Fischer (2006), whereby a learner externalises their view. However, learners do not commonly engage in self-explanations autonomously (Renkl, 1997), suggesting the need for learner support (Renkl, 2005). Moreover, self-explanations which are supported by prompting outperform unprompted self-explanations (Chi et al., 1994). As such, this study investigated the effect of prompting on the level of transactive dialogue of groups during a CSG, and if there was any effect on knowledge gain.

The Current Study

The aim of the current study was to investigate the effect of transactive dialogue prompting on the effectiveness of a collaborative serious game among Irish first-year students. The study was conducted at a secondary school in Ireland using a tablet-based collaborative game about proportional reasoning. The research was conducted through a pre-test, post-test, experimental design. Participants were divided into groups of four to play the game. Groups were then assigned to the experimental or control conditions. The experimental and control groups both received the serious game. Each group got the chance to play the game twice. The experimental group also received in-game prompts whereas the control group played the game without prompts. The group discussions were recorded using an audio recorder. The discussions of the groups were analysed as per the classifications used by van Dijk et al. (2013) as based on the work of Weinberger and Fischer (2006). The group discussions were analysed to determine if there was a difference in the occurrence of transactive dialogue between conditions. Knowledge tests examined the level of knowledge of proportional reasoning of the participants before and after playing the game. It was expected that the inclusion of transactive dialogue prompting would increase the level of transactive dialogue and knowledge gain for students in the experimental group more than that of the control group.

As such, the following research questions were posed:

1. What is the effect of transactive dialogue prompting on knowledge gain in a collaborative serious game about proportional reasoning among Irish first-year students?
2. What is the effect of transactive dialogue prompting on the level of transactive dialogue in a collaborative serious game about proportional reasoning among Irish first-year students?

Method

Participants

The sample included 84 first-year secondary school students (N_{male} = 38 and N_{female} = 46), aged 11 to 13 (*M* = 13.05, *SD* = 0.366). All participants were from six first-year classes at one secondary school in Ireland. An informed consent form was approved by the BMS Ethics Committee at the University of Twente for use in the study. Only students whose parent or guardian gave active consent to participate in the research and for the child to be audio-recorded were included.

Participants were divided into 21 groups of four by their teachers. These groups were randomly assigned to either the experimental (*n* = 11) or control (*n* = 10) conditions. The experimental groups played a version of the game which included prompting, and the control groups played a version without prompts. The experimental groups consisted of 24 boys and 20 girls. The mean age of the experimental groups was 13.09 (*SD* = 0.388) The control groups consisted of 14 boys and 26 girls. The mean age of the control groups was 13.02 (*SD* = 0.341).

Instruments

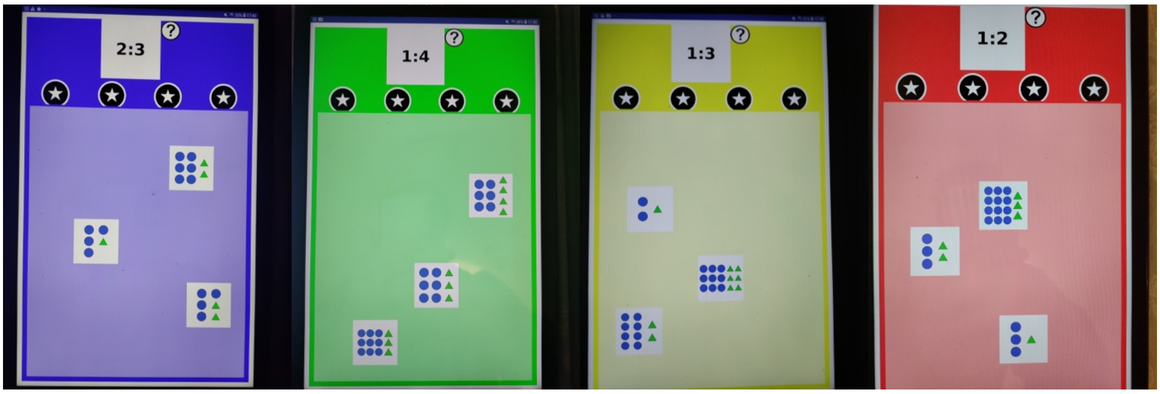
The Game

A tablet-based game about proportional reasoning was developed as part of this study. It is an adaptation of the *Collaborative Words* research app. Collaborative Words is a multi-tablet game about phonological awareness (van Beurden, 2021). It employs collaborative learning to facilitate the learning of rhyme and word-onset. Collaborative Words is classified as a game because it has goals, interactivity and provides feedback (Vogel et al., 2006, Wouters et al., 2013). For this study, the app was repurposed, retaining the core game mechanic, and replacing the educational content of the game to be about proportional reasoning.

The Collaborative Words game can be played with three or four participants. Groups of four were chosen for this study. Each group member was assigned a tablet with which to play the game. A fifth device was used to start and stop the game and to record performance measure logs which were later analysed. The game began with twelve cards evenly divided amongst the tablets. Each card contained a visual representation of a proportion (Figure 1). Each tablet had a different coloured background and a fixed target proportion displayed at the top of the screen. The cards were sent between the tablets by tapping on the card and selecting the target tablet from a pop-up menu. Each tablet displayed four status bars (Figure 1), containing a circle with a star in it. Each one had a colour which corresponded to the colour of the tablets. These status bars began to fill up when the correct cards were sent to the correct tablets, allowing players to monitor their progress. The aim of the game was for all twelve cards to be sent to the correct devices.

Figure 1

Photographs of the screen display



Note. The example above is of the ratio task from the game. The cards always originate on the same device when the game is launched but their position on the screen may vary.

The tablets were positioned flat on the table (Figure 2), such that all players could see the state of their groupmates' displays. Each player only had control of their own device, which meant that they had to verbally communicate to request the correct cards from their groupmates. When learners must rely on each other to complete a task, this is called task-outcome interdependence, and it is associated with increased knowledge gain from collaborative activities (Kirschner et al., 2014). The game aims to encourage transactive dialogue, as students should externalise their thinking and engage in knowledge co-construction to complete the tasks.

Figure 2

Photograph of tablet setup

Note. The screens appear blank because this photograph was taken before the game was fully launched.

Learning Content. In repurposing the game, three separate tasks were created, each focused on specific mathematical concepts: ratios, fractions, and percentages. The educational content of the game was based on the learning objectives of the Junior Cycle Mathematics Curriculum published by the Department of Education in Ireland. A key learning objective was for students to recognise "equivalent representations of rational numbers so that they can use and understand ration and proportion" (National Council for Curriculum and Assessment, 2018, p. 15). The game was designs to allow students to practice the following constructs of proportional reasoning: understanding the concept of proportions, recognising equivalent proportions, understanding how quantities can be scaled up or down while maintaining the same proportion, comparing proportions, and interpreting multiple representations of proportions. An informal needs assessment conducted with a mathematics teacher at the school also directed the selection of instructional material for the game. This helped the learning content to align with the educational needs of the students.

Each of the three tasks contained twelve cards to be sorted. For every target proportion there were three distinct visual representations of the proportion in increasing levels of complexity. For example, in the ratio task (Figure 1), the target proportion *1:2* was represented in three ways: one green triangle with two blue circles, two green triangles with four blue circles, and three green triangles with six blue circles. A similar pattern was repeated for all proportions across all three tasks.

During the game, each group played the ratio, percentage, and fraction tasks in the game. The complexity of cards was evenly distributed as much as possible to ensure equal difficulty between devices. Students also had to flexibly convert between and simplify visual and textual representations of proportions. For example, a correct move in the game may have involved a student recognising that a card containing an image of two green triangles and six blue circles was a proportion which can be simplified to *1:3* and sending the card to the appropriate target tablet. The game could be completed with a minimum of twelve moves if all moves were correct. It was possible for more than twelve correct moves to be made during the game. For example, if a student makes the correct move, but the same card is then sent to another tablet (incorrect move), it will require an additional correct move to send it back to the correct device.

Experimental Version of the Game

Prompts were included in the game for the experimental group. The control group played the game without prompts. The aim of the prompts was to initiate transactive dialogue in the group by eliciting explanations from the students about their decisions in the game. An open-ended prompt was used which read, "Please explain why you are sharing this card with your groupmate." An open-ended prompt was chosen for several reasons. Firstly, in a practical sense, it best fitted the customisation to the game which was achievable during the scope of this study. Secondly, open-ended self-explanation prompts have been found to elicit incomplete or incorrect explanations (Renkl, 2002; Wylie & Chi, 2005). While incomplete or incorrect self-explanations alone are associated with poor learning outcomes (Bethold et al., 2009), they provide a possible fertile ground for transactive dialogue, as students engage in knowledge co-construction by critiquing and arguing with the explanations of their groupmates. Thirdly, an open-ended prompt was chosen to minimise the level of directive instruction, with the aim of facilitating more organic externalisations from the students.

The prompts appeared on a screen overlay when a student chose which card they wanted to send, alongside the list of tablets they could send the card to. This means that a student in the experimental group saw the prompt multiple times (whenever they chose to send a card to a groupmate) and differed between students depending on how many moves they attempted.

Knowledge Tests

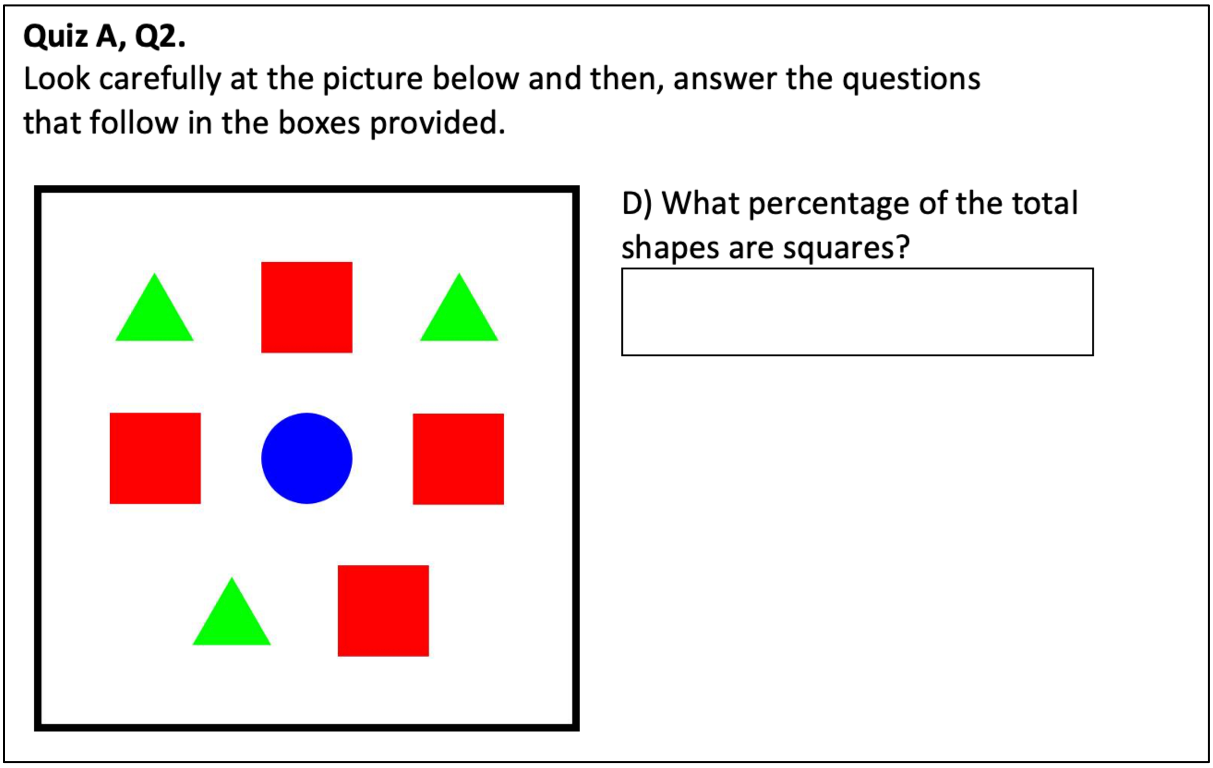
Knowledge tests were used before and after the experiment. The knowledge tests, like the game content, were based on the Junior Cycle Mathematics Curriculum (National Council for Curriculum and Assessment, 2018). Two parallel versions of the test (A and B) were created which both contained eight items each and were designed to be of equal difficulty. Figure 3 shows an example of a task from the knowledge tests. The full tests are included in the appendix. Part one contained three pair-matching items and part two contained five close-ended, quantitative items.

The knowledge tests were designed to measure the same constructs as the learning material in the game. Namely, understanding the concept of proportions, recognising equivalent proportions, understanding how quantities can be scaled, comparing proportions and being able to interpret different representations of proportions. In both tests, two test items involved a proportion which appeared in the game and six test items which involved a proportion that was not in the game, to introduce a level of near transfer.

Scores on the knowledge test could range from zero to eight, with one point for each item, and scores given for correct answers only. The difference was calculated to represent knowledge gain which could range from negative eight to eight. To account for any variation in difficulty and order effects between the tests, a counterbalanced design approach was used. Ten of the groups did test A for the pre-test and test B for the post-test, while the remaining eleven groups did test B for the pre-test and test A for the post-test. Cronbach's Alpha was .537 for test A, and .559 for test B.

Figure 3

Example of a task from the knowledge test



Measuring Transactive Dialogue

During the game, audio of the group discussions was recorded. The audio was edited to remove any utterances of personally identifying information. The recordings of the groups were analysed for the frequency of transactive dialogue. This was done by first dividing the audio into three parts, relating to the three tasks in the game. The audio for each task was then divided into four segments of equal length, such that each segment lasted approximately twenty-five percent of the total time spent on that task for each group.

For each segment it was noted if both low-level and high-level transactive dialogue had occurred or not. A segment was only classified as transactive if the transactive dialogue was also on-task. For example, if a segment contained low-level transactive dialogue it scored one for low-level dialogue, and if not, it scored zero. This resulted in a score which could range from zero to twenty-four (two trials with three tasks and four segments) for each level of transactive dialogue for each group. The audio was coded for the level of transactive dialogue using an adapted coding scheme (Table 1) based on the scheme by van Dijk et al. (2013), which is adapted from the work of Weinberger and Fischer (2006). The dialogue was coded only at the group level.

Coding was first conducted with respect to the five levels of transactive dialogue, but the resulting inter rater reliability was too low for use. The coding scheme was further modified so that information sharing, and quick consensus building were coded as 'low' and transactivity was coded as 'high', where low and high refer to the level of transactive dialogue. A second rater coded approximately 14% of the audio. The inter-rater reliability was assessed in SPSS using Cohen's Kappa. The Kappa Statistic was 0.822 (p = <.001) indicating strong agreement between the raters (Cohen, 1995).

Table 1

Coding scheme for the transactive dialogue of the audio

Categories	Description	Example
Low		
Information sharing		
Externalisation	Externalising content to collaborative partner	This is a half…
Elicitation	Requesting information from collaborative partner	I need a two is to one…
Quick consensus		
Agreement	Quick consensus building: agreeing with partner	Okay
Disagreement	Disagreeing without showing comprehension	No
High		
Transactivity		
Integrating	Evidence that the speaker learned from partner	I see what you mean…
Critiquing	Critiquing or correcting input from partner	Okay, but isn't it like…?

Measuring Game Performance

A log file was created for each task during the game. The log file recorded the number of incorrect moves made by a group and the time taken to complete the game. The timer began when all the students were ready and the game was initialised by the researcher, who simultaneously announced that the task had begun. The timer stopped instantly when all the correct cards had been sent to the correct devices. The number of incorrect moves and the time taken were used to inform about the performance of the group. The are many variations of ways in which the measured performance measures can interact with the main research questions. The time taken to complete a task could reflect the level of engagement of a group (Jennett et al., 2008), with students deliberating decisions and engaging in dialogue. Conversely, the time taken could indicate that the game was too easy and required little engagement or was too difficult and that students had difficulty collaborating. Incorrect moves may be an indicator of better group performance in the game, with more incorrect moves indicating that the group had more difficulty with the game. A higher number of incorrect moves could also indicate opportunities for increased reflection in the group, offering students a chance to reflect on the input of their groupmates, and engage in transactive dialogue. The performance measures will be discussed in the context of the study findings in the discussion section.

Procedure

The data collection took place over one week. Only students who returned the informed consent forms were included. Groups were taken one by one from their classes to a small room to take part in the experiment. This was done to reduce the amount of background noise in the audio recordings and to avoid distractions from other groups simultaneously discussing their reasoning.

Each group participated in two sessions which were not time constrained but ended when the students completed the game and knowledge tests. The time to complete both sessions ranged from seven minutes for the fastest group to twenty-three minutes for the slowest group. The first session began with the pre-test and afterwards the participants played the game. In the second session, participants began by playing the game and subsequently completed the post-test. The experimental group played a version of the game with prompting and the control group played the game with no prompt. The pre-tests and post-tests were completed individually by the participants and the game was played as a group.

Data Analysis

Measurements of knowledge gain, low level dialogue, high level dialogue, incorrect moves and time on task were checked for normality using Shapiro-Wilk tests in SPSS. Results indicate that all measurements violated the assumption of normality (Table 2), hence non-parametric tests were chosen for all following analyses.

An explorative correlation analysis was also conducted in SPSS between all study variables using Pearson's *r*. This was done to investigate if there were any other relationships between variables which could serve the interpretation of the data. For this analysis, the results of the knowledge test data were recoded into group scores, as knowledge test data was collected at individual level and both transactive dialogue data and game performance data were collected at group level.

Table 2

Results of Shapiro-Wilk tests for transactive dialogue and game performance data.

Measure	Shapiro-Wilk		
	W	*df*	*p*
Knowledge gain	.83	84	<.001
Low level dialogue	.36	21	<.001
High level dialogue	.31	21	<.001
Incorrect moves	.56	21	<.001
Time on task	.78	21	<.001

Results

To assess whether both conditions were comparable in age, prior knowledge and total moves made in the game, conditions were compared. A Mann-Whitney U Test was used with condition as the independent variable and prior knowledge as the dependent variable. The output showed no significant difference in prior knowledge between conditions, $U = 842$, $z = -0.404$, $p = .686$, with an effect size of $r = .04$. An independent samples t-test was used with condition as the independent variable and age as the dependent variable. No significant difference in age was found between the experimental ($M = 13.08$, $SD = 0.388$) and control ($M = 13.01$, $SD = 0.341$) conditions, $t(82) = 0.871$, $p = .386$. A Mann-Whitney U Test was used with condition as the independent variable and total moves as the dependent variable. The result showed no significant difference in total moves made between conditions, $U = 33$, $z = -1.549$, $p = .132$, with an effect size of $r = .33$.

Learning Outcomes

The results of the knowledge tests were analysed to assess the learning outcomes before and after participants played the game (Table 3). A Wilcoxon signed rank was performed with time as the independent variable and test score as the dependent variable. The test did not reveal a significant difference in knowledge test scores before and after the intervention, $z = -1.28$, $p = .201$, with an effect size of $r = .13$. The results of the knowledge tests were also analysed for differences in scores between conditions using a Mann-Whitney U Test with condition as the independent variable and score difference as the dependent variable. The results of the test did not indicate a statistically significant difference between the experimental group and the control group, *U* = 821, *z* = -0.588, *p* = .556, with an effect size of *r* = .06.

Table 3

Medians, means and standard deviations of the pre-test, post-test, and knowledge gain for all students.

Measure	Control (*n* = 40)		Experimental (*n* = 44)		Total (*n* = 84)	
	M (SD)	*Mdn*	*M (SD)*	*Mdn*	*M (SD)*	*Mdn*
Pre-test score	7.35 (0.94)	8	7.36 (1.16)	8	7.35 (1.06)	8
Post-test score	7.7 (0.6)	8	7.61 (0.78)	8	7.65 (0.7)	8
Knowledge gain	0.35 (1.02)	0	0.25 (1.27)	0	0.29 (1.15)	0

A large portion of students (53 out of 84) achieved the maximum score on the pre-test. As these students could not demonstrate an improvement in test score after playing the game, additional analysis was performed which only included students with a score of less than the maximum of eight on the pre-test. Descriptive statistics are displayed in Table 4. A Wilcoxon signed rank test, with time as the independent variable and test score as the dependent variable, revealed a statistically significant increase in test scores *after* playing the game, *z* = -4.483, *p* = .001, with an effect size of *r* = .805. To investigate the effect of condition for this subset of participants, a Mann-Whitney U Test was performed, with condition as the independent variable and test scores as the dependent variable. The results revealed there was no significant difference between conditions, *U* = 96.5, *z* = -0.950, *p* = .377, with an effect size of *r* = .17.

Table 4

Medians, means and standard deviations of the pre-test, post-test, and knowledge gain for selected students.

Measure	Control (*n* = 17)		Experimental (*n* = 14)		Total (*n* = 31)	
	M (SD)	*Mdn*	*M (SD)*	*Mdn*	*M (SD)*	*Mdn*
Pre-test score	6.47 (0.87)	7	6 (1.24)	6.5	6.25 (1.06)	7
Post-test score	7.64 (0.7)	8	7.5 (0.65)	8	7.58 (0.67)	8
Knowledge gain	1.17 (0.95)	1	1.5 (1.16)	1.5	1.32 (1.04)	1

Transactive Dialogue

Table 5 shows the means, standard deviations, and medians for low and high level transactive dialogue from the audio recordings. A Wilcoxon signed rank test was used to compare the medians of the low level and high level transactive dialogue. The test revealed a significant difference, $z = -3.922$, $df = 19$, $p < .001$. The findings show that low level dialogue was more common than high level dialogue.

Table 5

Means and standard deviations of the levels of transactive dialogue of the audio data.

Measure	Control (*n* = 10)		Experimental (*n* = 11)		Total (*n* = 21)	
	M (SD)	*Mdn*	*M (SD)*	*Mdn*	*M (SD)*	*Mdn*
Low level dialogue	3.21 (1.46)	4	3.25 (1.47)	4	3.23 (1.46)	4
High level dialogue	1.05 (1.11)	1	0.9 (1.14)	0.5	0.97 (1.12)	1

A Mann-Whitney U Test was used to compare the conditions for low and high level transactive dialogue. The results did not indicate a statistically significant difference between conditions for low level transactive dialogue, $U = 1945$, $z = -0.230$, $p = .818$, with an effect size $r = .05$. Similarly, no significant difference was found between conditions for high level dialogue, $U = 1798$, $z = -0.946$, $p = .344$, with an effect size, $r = .206$.

Game Performance

Data was captured through data logfiles during gameplay to inform about game performance. The time taken to complete a task and the number of incorrect moves per task were recorded (Table 6).

Table 6

Means and standard deviations of the game performance data.

Measure	Control (*n* = 10)	Experimental (*n* = 11)	Overall (*n* = 21)
	M (SD)	*M (SD)*	*M (SD)*
Incorrect moves	7.26 (8.33)	6.86 (14.53)	7.05 (11.94)
Time (seconds)	142.87 (97.92)	134.69 (111.79)	138.58 (105.07)

The results of a Mann-Whitney U test indicated a statistically significant difference between conditions for incorrect moves, $U = 1460$, $z = -2.556$, $p = .011$, with an effect size $r = .022$, showing that the experimental groups made less incorrect moves than the control groups. Conversely, no significant difference was found between conditions for time taken per task, $U = 1805$, $z = -0.855$, $p = .393$, with an effect size, $r = .070$.

An explorative correlation analysis of the study variables was conducted using Pearson's *r* in SPSS (Table 7). Significant correlation was found between low level and high level transactive dialogue, as well as between high level dialogue and time taken.

Table 7

Correlations between variables

Variable	*n*	*M*	*SD*	1	2	3	4	5	6
1. Pre-test score	21	29.428	2.749	-					
2. Post-test score	21	30.714	1.230	.156	-				
3. Incorrect moves	21	42.333	44.723	-.005	-.027	-			
4. Time taken	21	831.541	244.981	-.005	-.090	.348	-		
5. Low level dialogue	21	50.619	22.337	.026	.087	-.279	-.052	-	
6. High level dialogue	21	7.952	5.860	.104	-.037	-.067	.462*	.688**	-

Note. *$p < .05$. **$p < .01$.

Discussion

The aim of this study was to investigate if transactive dialogue prompting increases the effectiveness of a collaborative serious game for Irish first-year secondary school students. The inclusion of prompting did not improve the effectiveness of the game for students in the experimental condition, but the findings demonstrate that students were able to learn from the game when excluding students who achieved a maximum score on the pre-test. Most of the groups did engage in transactive dialogue, but there was no significant increase in high or low level transactive dialogue due to prompting.

It was expected that learner knowledge would increase after playing the game and that the knowledge gain of those in the experimental condition would be greater than those in the control condition. However, no significant difference was found between the conditions for knowledge gain. This contradicts findings from Chi (1996) where self-explanation prompts during knowledge co-construction were found to be effective for learning. There are several possible explanations for this result. Firstly, the prompt used in this study was an open-ended prompt. Detailed prompts which provide additional learner support have been shown to be more effective than more simple prompts (Wichmann & Leutner, 2009, p.122). In addition, studies suggest that open-ended prompts are suitable for older students (Alfieri et al., 2011). The prompt used in this study may not have provided the right level of support to facilitate self-explanation.

Another explanation may be that the game was not appropriately complex. A learning task must be sufficiently complex to warrant effective collaborative learning (Kirschner et al., 2014). If a learning task can be easily completed solitarily, the increased cognitive load of additional collaborative processes, such as discussion and delegation, can negate the benefits of collaborative learning (Kirschner et al., 2014).

A moderate, positive correlation was found between time taken and high-level transactive dialogue, suggesting that groups which engaged in more high-level transactive dialogue spent longer playing the game. This finding could support the idea that high-level transactive dialogue groups were engaged in other collaborative processes which may have hindered their knowledge gain. Though the prompt was expected to increase knowledge gain for the experimental groups, the knowledge gain was hypothesised to be achieved through an increase in transactive dialogue.

The expectation of the second research question was that the inclusion of the prompt would increase the level of transactive dialogue. The results show that transactive dialogue did occur during the gameplay, but a significant difference was not found between conditions. This indicates that the prompting did not increase the level of transactive dialogue. This finding is congruent with the lack of knowledge gain, as any increased knowledge gain for the experimental groups would have been expected to stem from an increased level of transactive dialogue (Teasley, 1997; Weinberger & Fischer, 2006).

There are several possible explanations for this result. Firstly, as discussed in relation to the lack of knowledge gain, the open-ended design of the prompt may not have provided adequate support (Wichmann & Leutner, 2009, p.122), particularly for younger students (Alfieri et al., 2011). Secondly, students find it very difficult to explain their thinking when given open explanation prompts, often giving incorrect or partially complete explanations (Berthold et al., 2009). Moreover, providing learner support for collaborative dialogue works through interrupting the natural dialogue of the group and directing it towards communication which supports learning (van der Meij et al., 2019).

The lack of increase in transactive dialogue between conditions suggests that the prompt failed to direct the group's unprompted dialogue towards transactivity. Furthermore, explanations given by students during successful group collaboration are mostly highly relevant to the preceding dialogue of the group (Barron, 2003, Weinberger & Fischer, 2006).In the current study, students often talked at the same time, indicating that they may have been more focused on explaining the contents of their own tablet rather than participating in transactive dialogue by engaging with the explanations that were offered by their group mates. Low-level transactive dialogue, such as externalisation and elicitation, is not necessarily related to the input of other group members, whereas high-level dialogue only occurs when learners engage with each other's input (Weinberger & Fischer, 2006). The results show that the majority of transactive dialogue during the study was low-level, which may support the idea that students were more focused on explaining their own ideas rather than engaging in the group dialogue. However, a strong, positive correlation was found between low-level and high-level transactive dialogue. This may suggest that low-level dialogue is a pre-requisite for high-level dialogue, or that students who are capable of a lower level of transactive discussion are also more likely to be capable of a higher level of transactive dialogue. Although prompting failed to increase the level of transactive dialogue, the incorrect moves suggests that prompting did affect game performance.

The number of incorrect moves was recorded to inform about the behaviour and performance of the groups during the game. The results show that experimental groups made significantly less incorrect moves. A higher number of incorrect moves would have meant that a group received the prompt more times. However, no effect was found between incorrect moves and transactive dialogue or knowledge gain.

It is possible that the prompting may have encouraged students to think more about their moves; paying closer attention to the game, while choosing not to verbalise their thinking. This increased focus could have resulted in fewer incorrect moves without increasing the level of transactive dialogue of the group.

This finding could also support the argument that students were more focused on their own tasks than on engaging in transactive dialogue. Teasley (1997) found that transactive dialogue increased performance even during individual learning activities, as learners can reason with their own externalisations. Similarly, students may have individually benefitted from their own non-verbal, self-explanations, leading to an increased performance during the game, but again without increasing the level of transactive dialogue of the group. The improved performance of the experimental groups during the game might suggest that, as discussed earlier, the transactive dialogue of the experimental groups was more relevant to the preceding discussion and thus more beneficial (Barron, 2003).

Implications

Educators could make use prompting in collaborative games, since it didn't have any negative effects on knowledge gain or the level of transactive dialogue. While the inclusion of prompting didn't foster transactive dialogue or learning in this study, it did minimize errors, which might indicate more thoughtful processing. Over time this could result in benefits. Failures in maths and science can undermine students' self-confidence which has a negative effect on their learning outcomes (Usher et al., 2019). Maintaining learner self-confidence is important as it can increase motivation and make learners' more likely to pursue a learning task (Lorsbach & Jinks, 1999). Future studies with longer interventions could help us learn more about this.

Another implication of this study is the adaptation of *Collaborative Words* app to be a game about proportional reasoning. As discussed earlier, collaborative games present opportunities for deep learning because they are motivating (Tobias et al., 2014) and encourage collaborative discussion (van der Meij et al., 2019). While prompting did not contribute to its effectiveness, the results show that both learning and transactive dialogue did occur during the game. As such, the app could be repackaged as a *Collaborative Proportions* game for use in classrooms or in further studies.

Limitations and Further Research

A ceiling effect was observed in the knowledge test data, with 63% of students achieving a maximum score on the pre-test and 75% achieving the same on the post-test. This indicates that the knowledge tests were not appropriately challenging for a significant portion of the students. The ceiling effect may have contributed to the low reliability of the tests. Cronbach's Alpha was calculated to be .537 for test A and .559 for test B, indicating insufficient reliability for both tests. According to Kline (2013), a Cronbach's Alpha of .7 and above is considered acceptable for ability tests. The lack of reliability in these tests raises concerns about drawing conclusions regarding the students' knowledge gain. As a result, while knowledge gain could be demonstrated for students who did not achieve full marks on the pre-test, the tests failed to assess any potential knowledge gain for the remaining students. As such, any effect of the intervention on knowledge gain for these students may have gone unnoticed. A more rigorous pilot-test of the knowledge tests would have better informed their design, ensuring that they adequately differentiated between students' knowledge levels.

The test environment may also have impacted the results of the study. Firstly, the positioning of students around the table made it possible for them to copy answers from one another during the testing. This introduces a potential confounding factor that could affect the validity of the knowledge test results. As such, the data may not reflect the effect of the intervention as students' scores on the knowledge tests might not be accurate. Similarly, bringing the students from their classroom to the test room in groups of four, may have affected their performance by resembling an exam. Test anxiety is linked with a reduction in learning outcomes and self-motivation (Stöber & Pekrun, 2004). This could have contributed to inaccuracy regarding the measurement of the students' true knowledge, which may have obfuscated any effect of the prompt.

By analysing transactive dialogue at group level, this study did not examine the heterogeneity of participation of the participants, nor could it link knowledge gain to an individual's level of transactive dialogue. While small group activities, such as this study, can facilitate more even participation (Cohen & Lotan, 1995), often the benefits of knowledge co-construction are confined to certain learners (Weinberger & Fischer, 2006). Furthermore, the ability to provide self-explanations independently is correlated with academic ability (Chi. et al, 1994). It may have been the case that the students who attained maximum scores on the pre-test were predominantly the same students that engaged in transactive dialogue, thereby benefitting the most from the collaborative knowledge co-construction. In this case, any increased knowledge gain of these students could not be measured as they scored full marks on the pre-test.

While this study examined the level of transactive dialogue, the relevancy of the low-level transactive dialogue to the preceding discussion was not measured. Future research should examine the effect of the relevancy of the low-level transactive dialogue. Barron (2003) provides a coding scheme for measuring the relevancy of group dialogue. Future studies could gain additional understanding of low-level transactive dialogue by measuring the relevancy of dialogue and how it relates to the effectiveness of overall transactive dialogue in collaborative learning.

Conclusion

This study looked at the effectiveness of transactive dialogue prompting in a collaborative serious game for Irish first-year students. While the game facilitated learning and transactive dialogue, the inclusion of prompting did not lead to a significant improvement in knowledge gain or the level of transactive dialogue. These findings challenge previous research that suggested the effectiveness of self-explanation prompts during knowledge co-construction. The open-ended nature of the prompt used in this study may have provided insufficient support for self-explanation, particularly for younger students who may struggle with providing detailed explanations. While the prompt did not yield the expected effects, this study contributes to the understanding of transactive dialogue prompting in CSGs. It is evident that further research is needed to better understand the factors influencing the impact of prompts on transactive dialogue during CSGs, and to develop more targeted interventions for enhancing their learning outcomes.

In conclusion, this study highlights the complexities involved in fostering collaborative learning through promoting transactive dialogue. Despite the overarching findings of this study, the observed learning gain and effect of prompting on incorrect moves provide encouragement regarding the use of CSGs and transactive dialogue prompting therein.

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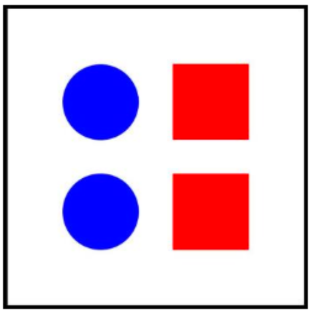
Appendix

Quiz A Group: ______ DOB: ____/____/____

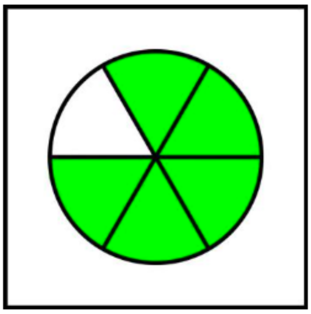
Name: ____

Quiz A, Q1.

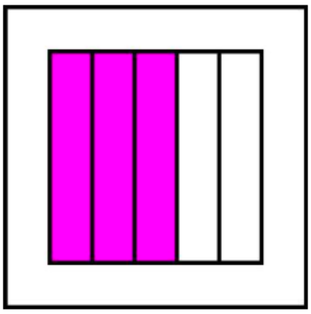
Look carefully at the pictures and then, draw a line to match each picture to the correct fraction, percentage, or ratio.



60%



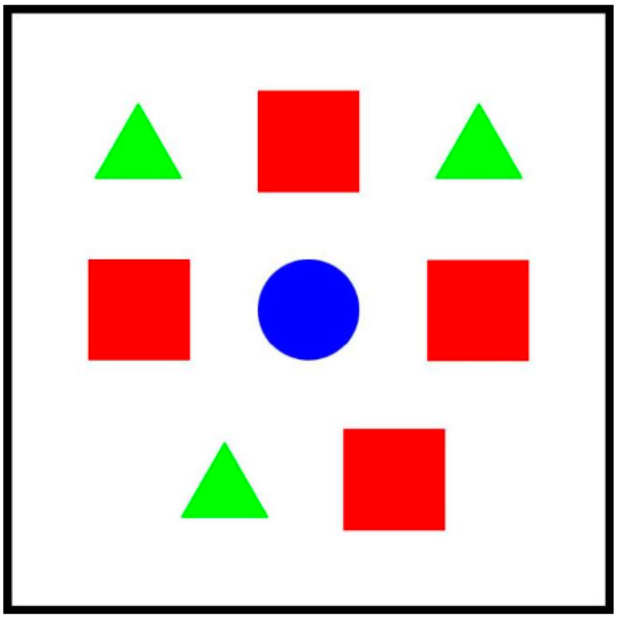
1:1



5/6

Quiz A, Q2.

Look carefully at the picture below and then, answer the questions that follow in the boxes provided.



A) What is the ratio of squares to circles?

B) What is the ratio of triangles to squares?

C) What is the ratio of triangles to circles?

D) What percentage of the total shapes are squares?

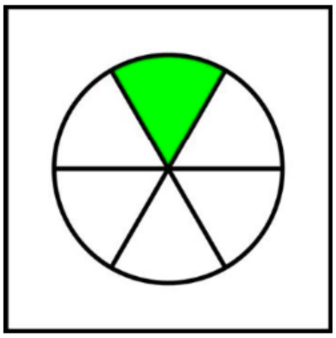
E) How many of the total shapes are triangles? Give your answer as a fraction.

Quiz B Group: ______ DOB: ____/____/____

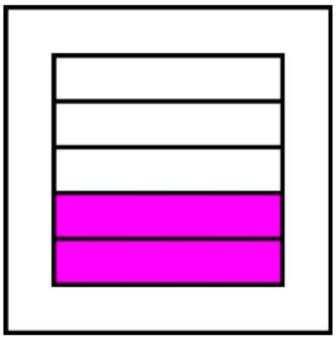
Name: ______________________________________

Quiz B, Q1.

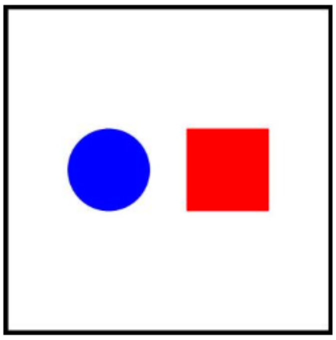
Look carefully at the pictures and then, draw a line to match each picture to the correct fraction, percentage, or ratio.



1:1



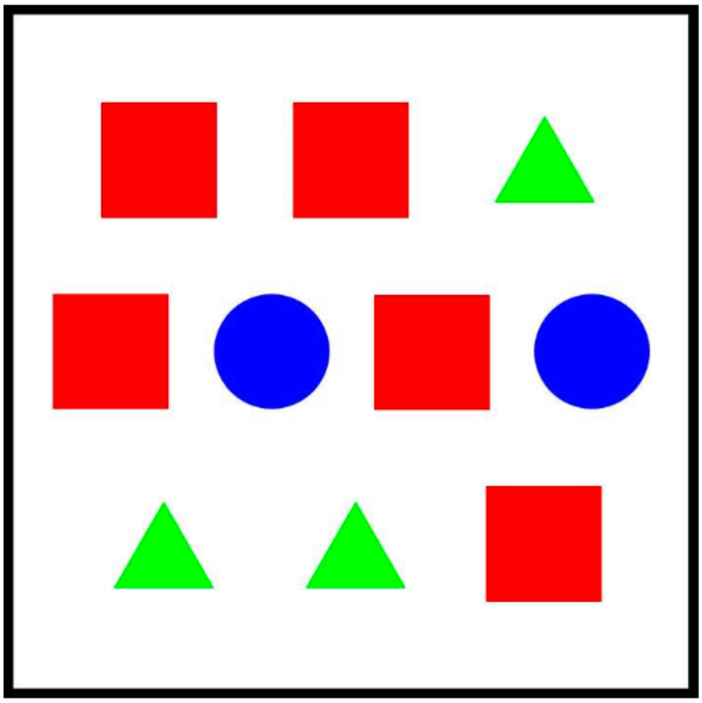
1/6



40%

Quiz B, Q2.

Look carefully at the picture below and then, answer the questions that follow in the boxes provided.



A) What is the ratio of squares to circles?

B) What is the ratio of squares to triangles?

C) What is the ratio of circles to triangles?

D) What percentage of the total shapes are squares?

E) How many of the total shapes are circles? Give your answer as a fraction.