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Encouraging Diversity in Computer Science among Young People: Using a Games Design Intervention based on an Integrated Pedagogical Framework

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***Abstract*— This research to practice full paper presents the results from using a games design intervention to encourage diversity in the uptake of computer science by young people, explore stereotypes with them and increase their awareness of careers in the sector. The intervention is based on an integrated pedagogical framework appropriate for use with primary age school children (age 7 – 11 years). Despite the increasing use of technology, the percentage of young people taking up a computer science education-career path remains stubbornly low in the UK and across a number of other countries, particularly for females and those from lower socio-economic backgrounds. Previous research suggests that games can be used to generate interest and engage young people with computer science. Other studies advocate targeting young people at an earlier age (7 years or below) and sustaining engagement throughout their education to widen participation in a particular sector. In this intervention, young people designed and developed individual games through a three stage process: design and story development; game building; testing and evaluation. This research adopts elements from two pedagogical learning theories Direct Instruction and Cognitive Constructivism to create an integrated pedagogical framework to support the game creation process and enable effective learning. This provides an approach that can cater for a range of participants' abilities along the novice-expert spectrum and provide an engaging and age appropriate educational experience.**

The intervention was completed in two cycles: cycle 1 consisted of a series of workshop sessions with 20 young people aged 9-10 years over a period of 5 weeks; and cycle 2 was a single session with 19 young people aged 7-11 years. A quasi-experimental approach was adopted for evaluating the intervention using the following instruments; pre and post questionnaires, planning sheets, the games created by the participants and a set of already developed engagement factors. Results show an increase from 5% to 25% in participants' aspiration towards a computer science career. 45% of the young people also knew more careers in the game industry post-intervention. Girls chose a variety of diversity in their lead characters while boys chose mainly male human lead characters in the games that they designed. Participants' evaluation of each other's games using the engagement factors showed girls were more interested in receiving feedback than boys. This paper highlights the effectiveness of combining different learning approaches to provide an age appropriate intervention. It also presents evidence on the positive effect of using games in the classroom to explore stereotypes, and learn about, and encourage career choices in computer science.

Keywords — digital games, children, diversity, scaffolding, direct instruction, cognitive constructivism, career guidance

I. INTRODUCTION

Despite the increasing use of technology, the percentage of young people taking up a computer science education-career path is still low especially by under-represented groups. The UK Department for Education shows 0.4% of females chose to take computer science A-levels compared to 4.5% males in 2017 [1]. An independent review of computer science degrees in the UK [2] identified several recommendations for continual fit of computer science given the rapidly changing technological landscape. Two of the recommendations were ensuring foundational knowledge was acquired by students and generating increased awareness of careers within the field. These and other recommendations led to the formation of the Institute of Coding in the UK aimed at bridging the digital skills gap in the UK by 2022 [3]. The demand for computer science skills extends beyond the UK; a report by [4] showed over 60% of skills required by the highest paying jobs in the US were related to computer science. Together these highlight

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the need for greater uptake of computer science. The use of games is one way to generate interest particularly for young people.

Research also highlight the need for more attention in Science, Technology, Engineering and mathematics (STEM) literature on links between theories, research and practice [5, 6]. The purpose of this study is to outline an integrated pedagogical framework using a games design intervention to generate interest and uptake of computer science by young people, increase their awareness of careers in the field, explore stereotypes and encourage diversity.

II. USE OF GAMES FOR LEARNING

The use of games for learning also referred to as 'serious games' [6, 7] has been suggested to have impacted positively on young people's learning experiences [8, 9, 10]. Studies suggest that motivation to engage with specific subject topics are higher when there is an association between the subject topic to be learnt and how the content is expressed or presented through games [11]. For example relating a topic in mathematics with games [12] or use of shapes play to teach geometry [13].

There is also an increasing call to start engaging young people in STEM education and experiences at an early age [14. 15, 16]. Several research studies have approached serious games for learning from the perspective of young people playing the games [17, 18, 19] rather than building games. Studies involving young people as producers of games [20, 21] have concentrated on older children in secondary schools and above with less focus on the younger age group. One of the studies involving young children in game building [17] highlighted the use of mobile games to improve motivations for learning.

Studies also suggest some young people start thinking about careers and aspirations as early as primary school, aged 5 to 11 years [15]. These young people are largely influenced by their environments; the culture and stereotypes associated with what they know of the careers [22, 23]. The games design industry has predominantly been male dominated which has also reflected in games created; males portrayed in lead roles with females mainly in subordinate or supporting roles [20], contributing to the stereotypical perceptions of the computer science discipline. Games have been used in research studies to teach primary school children about STEM education [12, 24]. Other studies have explored the impact of games on mobile devices to learning a science concept for 4-5 year olds [10]. Games have been adopted for learning because of their likelihood to adapt a participant's mental mode to include experiences gained by interacting with games [7, 25]. One of the strategies for facilitating learning is by means of 'scaffolding' particularly for children [26], which can also be accommodated, within games for learning [7].

III. IMPORTANCE OF SCAFFOLDING TO YOUNG PEEOPLE'S LEARNING

Scaffolding has been described in learning literature as a support system to enable learners to achieve tasks set out in activities [7, 13, 27, 28]. This begins with some guidance and assistance that are then gradually withdrawn in order for the learner to work independently. Some research studies have highlighted the importance of scaffolding particularly for children's learning to acquire complex knowledge [7, 13, 26]. Scaffolding allows children to adapt the way they think to accommodate new content or knowledge presented. Reference [28] adopted a scaffolding model to show how facilitators can direct children's attention to specific learning content during experiential activities. Links between pedagogical learning theories and game based learning are still unclear. Some researchers [29] have advocated for more research along these lines.

IV. PEDAGOGICAL LEARNING THEORIES

This study presents an integrated framework that focuses on two pedagogical learning theories used for career, science and technical education; Direct Instruction which is drawn from Behaviorism and Cognitive Constructivism which is drawn from Constructivism. Studies have compared the differences between the two learning theories or advocated for one or the other [30, 31]. Both learning perspectives agree on the impact of the environment and individual differences on learning but diverge on the importance accorded to those factors. While direct instruction highlights the environment, cognitive constructivism highlights the participant's role.

Direct Instruction learning theory advocates the use of clearly outlined guided instructions to promote learning. Direct Instruction is drawn from Behaviorism and focuses on explicit instruction, teaching and the role of the environment [11, 29]. This perspective is teacher focused and promotes accuracy; due to its step-by-step approach to develop expertise. It is useful to participants that have no or low levels of prior knowledge (novice level) [31]. A weakness of this perspective is the less important role assigned to individual differences [11].

Cognitive Constructivism on the other hand promotes knowledge building or learning through individual 'meaning making' [11]. This perspective suggest that knowledge is constructed as a function of external reality (experiences) and is focused on the student or participant. Teachers or facilitators act as just guides and not instructors. This perspective promotes creativity [31]. A weakness of this perspective is that it assumes participants have adequate prior knowledge (some level of expertise) to participate in the activities. This means that the learners need to have been explicitly taught some of this knowledge previously or gained it in another way. This might not always be the case.

Rather than focusing on which of the theories works better, the focus should center on which is the best process for the learners [18, 31]. Reference [26] suggests using a combination of strategies to bridge the gap between children's prior knowledge and acquiring more skills and knowledge. Cognitive constructivism is useful for problem solving and information processing by participants while direct learning is useful for reinforced practice [11]; both of which are necessary for use in games for learning.

Elements of learning theories described in this study are adopted from two studies; [32] for Cognitive Constructivism and [33] for Direct Instruction.

A. Direct Instruction

Reference [33] outlines several elements of Direct Instruction; four of which are applied in this study. The elements include structured instruction', 'conceptual mapping', interactive questioning and seatwork.

- **Structured instruction:** This refers to providing materials and presentations that have clearly stated objectives and structured content that could be easily understood and followed by participants [33]. If new knowledge is presented using a step by step approach at the participants' level of knowledge, it allows participants to practice using the new knowledge at their own pace and gain some level of proficiency [33, 34].
- **Conceptual mapping:** Conceptual maps provide a frame or template that guide participants and help structure their thoughts or expand on concepts in their mind [33]
- **Seatwork for individual practice:** This refers to times during a session where participants work independently using knowledge acquired and materials provided to perform tasks in order to achieve set objectives or outcomes. Some studies suggest providing enough materials and backup materials to cater for differences in speed and abilities of participants [33, 35].
- **Interactive questioning:** This refers to inclusion of practice or real world interaction opportunities where participants are able to reflect, practice and question what they have learnt [33].

B. Cognitive Constructivism

Reference [32] outlines four elements of cognitive constructivism and suggests that incorporation of these elements in activities or interventions makes them more effective. The elements are 'triggering prior knowledge', 'element of surprise', application of new knowledge and feedback.

- **Triggering prior knowledge:** This refers to activities that trigger participants' previous knowledge, skills and engages the mind [30, 32, 36, 37]. Studies suggests that new knowledge is better acquired when it builds on the pre-existing knowledge, experiences and understanding of participants [32, 38]. The activities used to trigger prior knowledge should make participants focus on what they already know that might be used in providing solutions to tasks given thereby making participants not only retrieve pre-existing knowledge but actively construct that knowledge in line with the new content to be learnt.
- **Element of surprise:** This refers to activities that uncover gaps in pre-existing knowledge needed to reach the desired learning outcome(s) which participants are made aware of. Pre-existing knowledge is not always accurate and could be based on misconceptions or information that is not true [32, 37]. Therefore, by introducing new information (element of surprise) that contradicts, or is counter-intuitive, to pre-existing knowledge, a level of discomfort is introduced which is referred to in the literature as 'Cognitive Dissonance' [32, 39]. Studies suggest that the level of cognitive dissonance should be moderate in order for participants to be motivated enough to alter the constructions of the flawed pre-existing knowledge [32]. If the level of cognitive dissonance is too high, it redirects learning focus from the new knowledge onto how to remove the discomfort; if it is too low, there would not be sufficient motivation to make any change.
- **Application of new knowledge:** These refer to activities that provide opportunity for participants to put into practice what they have learnt. By repeating actions or tasks taught, flaws are identified, corrected and learning is reinforced [32]. Reference [30] suggests that learning should occur in real world environments to provide participants with authentic experiences, which help them, construct meaningful and feasible mental structures relevant to the content taught.
- **Feedback:** Acquisition of knowledge is a continual process that cannot be observed directly but inferred from what is achieved [30]. To evaluate level of knowledge or understanding acquired, some form of assessment is necessary and feedback from such assessments provide participants opportunities to reflect on what they have learnt and the experiences gained [32]. Feedback is also useful because it helps the participants discuss the activities and their experiences with it [40]. Forms of assessments used in literature include self-assessments, assessment by teachers/facilitators and peers [11].

Combining elements from the two pedagogical learning theories provides an integrated scaffolding approach to support children. This is particularly important for the younger ones that might need more 'scaffolding' than the older ones. Together, these learning theories can cater for a range of participants' abilities along the novice-expert spectrum and provide an engaging and age appropriate experience. Table 1 shows the integrated framework.

V. METHODOLOGY

This study adopts an action research approach using a pre and post quasi experimental design. This approach is appropriate for problem solving and robust enough to accommodate for uncertainties as seen in real life settings. The action research approach was used in evaluating the current classroom situation recognizing the need to introduce career messages, tackle stereotypes and generate interest in computing in young people.

TABLE I. AN INTEGRATED PEDAGOGICAL LEARNING FRAMEWORK

	Integrated Pedagogical Framework		
	Learning Theory	***Elements of Learning Theories***	***Game Design Process***
1	Cognitive Constructivism	Triggering prior knowledge	Design and Story Development
2		Element of surprise	
3	Direct Learning	Structured instruction	
4		Conceptual mapping	
5	Cognitive Constructivism	Application of new knowledge	Game Building
6	Direct Learning	Seatwork for individual practice	
7	Cognitive Constructivism	Feedback	Testing and Evaluation
8	Direct Learning	Interactive Questioning	

Action research is also cyclical; this study was carried out over two cycles; cycle one and cycle two where an aim of cycle one was an intervention over several weeks and an aim of cycle two was a repeat of the intervention that could take place within one session. This was undertaken to explore the flexibility of the intervention.

The games design intervention is part of a wider sustained engagement agenda by NUSTEM, a STEM outreach group situated within the Faculty of Engineering and Environment, Northumbria University in the United Kingdom [41].

A. Participants

Participants were young people in primary schools in the North East of England. The intervention was delivered in cycles. Data was collected from 20 participants aged 9-10 over the course of 5 weeks in cycle one of the study. In cycle two, data was collected from 19 young people aged 7 – 11 in a one day session.

B. Structure of the Intervention

In cycle one, the first session introduced the children to computer games design and the software they were to use to create their own game. The children were shown how computer game designers developed games using story boarding. The second session had the children working independently on their games with assistance provided when needed. The third session involved guiding the children through the process of evaluating the games they created. They were introduced to some engagement factors in games which they used for peer evaluations. The fourth session allowed the children to reflect, modify and further develop on the games they created in light of the evaluations they conducted on each other's created games. The final session was a celebration of the work the children put into the sessions. Feedback was provided on the games and children had the opportunity to meet people working in the industry in an interactive question and answer session.

The aim of cycle two was to provide a condensed version of cycle one that could be taught in one combined session rather than taking place over several weeks. The focus of this condensed version was mainly on the activities from sessions one and two of cycle one to enable participants to concentrate on the games design itself with less time allocated to the remaining three sessions of cycle one

C. Evaluations

A quasi-experimental approach was adopted for evaluating the intervention using the following instruments:

- **Questionnaires (pre- and post-intervention):** Questionnaires were administered at the start of the intervention to capture demographic data (school, year group, gender); aspirations (participants were asked what they would like to be when they grew up) and knowledge of careers in the games industry (participants were asked to list as many jobs they could think, of people that worked in the games industry).
- **Games overview sheet:** The games overview sheet helped the children to outline concepts for their individual games and develop the story of the game
- **Planning Sheets:** The game planning sheet helped the children to map out the structure of the game they intended to create .
- **Games Created:** the games the children individually created were evaluated based on the type and diversity of the game characters and the gender of their lead characters.
- **Game Engagement Factors:** A previously developed set of game engagement factors [42] were used to help participants evaluate each other's games and to further develop their own games. These engagement factors were visual appeal, theme of the game, clarity of the goal of the game, how challenging the game was, rewards in the game, feedback in the game and creativity of the game.

VI. GAME DESIGN INTERVENTION

In this intervention, young people designed and developed individual games through a three stage process: *design and story development; game building; testing and evaluation*. This section describes the application of the integrated pedagogical framework in terms of the three stage process.

A. Design and Story Development

- At the start of the intervention, the children were asked about their knowledge of the games industry in terms of games, types of career and what such jobs might entail. The purpose of this activity was to *trigger prior knowledge*. Responses provided were captured using the pre-intervention questionnaire. The young people were also asked about their perceptions of how a game is produced.

- The children in this study were asked about their perception of what a games designer does as part of their job and other careers they knew in the industry. The *element of surprise* was introduced by showing the young people pictures and short videos that were tailored to counter common stereotypes around the games industry and associated careers.

- The children were provided with a step-by-step game creation *structured instruction* guide that explained the different aspects needed to create the game with pictographic representation for ease of understanding.

- *Conceptual mapping was* introduced using the planning and overview sheets. The children used the planning and overview sheets provided to build on their conception of a game expand its storyline and intended structure.

B. Game Building

- The children *applied the new knowledge* gained by creating their own games using the game engine 'Gamefroot'. The Gamefroot engine was chosen because it was child-friendly with drag and drop features for ease of use; games could be created online thereby eliminating the need to download at point of use; and the platform was able to accommodate a class group size.

- *Seatwork for individual practice* was applied by allowing the children time to work on their own building their games. Because the games created were based on the creative conceptualization of the children, they could work at their own individual pace. Children were also able to create more than one level of the game.

C. Testing and Evaluation

- After creating individual games, the children were allowed to play each other's games and evaluate the game they played against the engagement factors provided. Each child provided *feedback* on the game they evaluated. Also by playing each other's games, the children were able to reflect on changes they could make on their individual games to improve it.

- At the final session, results of the distribution of participants' choices in terms of the engagement factors were presented and discussed with the participants. The participants also had an *interactive questioning* session opportunity to meet a person that works in the games industry.

VII. Analysis

Analysis of the pre and post data from the questionnaires and the engagement factors was carried out using IBM SPSS 24 package [43]. Aspiration responses were sorted into two categories; STEM and non-STEM. Descriptive statistics were used for frequency counts of aspirations and number of careers known in the games industry. Data from the games overview sheet and games created were used to identify gender of lead characters and number of careers known in the industry. Fischer Exact test was used to test for gender differences in choice of lead characters and across the engagement factors. Fischer Exact test was appropriate for the analysis due to the small sample size.

VIII. Results

A. Aspiration to a STEM Job

- 25% (n=5) of the children aspired to a STEM career pre-intervention this number increased to 35% (n=7) post-workshop.

- 5% (n=1) of the children aspired to a career in computer science pre-intervention, this number increased to 25% (n=5) post-intervention.

B. Number of Jobs known

- 45% (n=9) of the children knew more jobs post-intervention compared to their responses pre-workshop; of this number, 33.3% (n=3) were boys and 66.7% (n=6) were girls.

- 25% (n=5, all boys) of the children knew the same number of jobs pre- and post-workshop.

- 30% (n=6) of the children mentioned fewer jobs post-workshop compared to their responses pre-workshop; 33% (n=2) of this number were girls.

- There was no statistical significance or no evidence to suggest a relationship between gender and number of jobs known pre- and post-intervention survey analysis at 5% (at $p <= 0.05$).

C. Choice of lead character

When the children designed their games, the following distribution was observed in the choice of lead characters:

- The girls chose a wide variety of lead characters – female, male and non-human, while the boys chose mainly male lead characters.

- 10% (n=2, both girls) of the participants chose a female lead character; no boys chose a female lead character.

- 65% (n=13, 3 girls, 10 boys) of the participants chose a male lead character.

- 15% (n=3, 1 girl, 2 boys) of participants chose more than one lead character.

- 10% (n= 2, both girls) of the participants chose an animal as their lead character.

- The data also suggested evidence of an association between gender and choice of lead character in the game (Sig. at $p=0.021$).

D. Engagement Factors

- Of all the engagement factors used (visual appeal, theme, clarity of goal, challenge, rewards, feedback) only the factor 'feedback' suggested some gender differences.
- 32% (n=7; 4 girls, 2 boys, 1 unknown) of children did not feel they got feedback from the game they evaluated.
- 32% (n=7; 6 boys, 1 unknown) of children felt they got much feedback from the games they evaluated of which
- 23% (n=5) were neutral regarding how much feedback they got from the game they were evaluating.
- There was evidence from this dataset to suggest an association between Gender and feedback obtained from games (Sig. at p=0.027)

IX. DISCUSSION

This research suggests evidence of the effectiveness of combining different learning approaches to provide an age appropriate intervention using games design intervention to improve uptake of computer science by young people. Results show an increase from 5% to 25% in participants' aspiration towards a computer science career. Findings are consistent with studies [16, 17] suggesting the influence of environment, culture and young people's perception of careers, on their aspirations towards those careers. By introducing the children to game design and providing opportunities to have authentic experiences with the games design process, the children are able to reassess their perceptions about careers in the games industry rather than relying on popular assumptions about the culture and stereotypes associated with those careers. Findings also align with studies [10] suggesting that this approach can lead to higher motivation to engage with a field or subject area as a result of interacting practically with the discipline area through the experience of games design. The results shows that there has been a positive impact among the young people on their awareness of careers in the games industry with 45% of the young people demonstrating that they know more careers in the game industry post-intervention.

Girls chose a variety of diversity in their lead characters while the boys chose mainly male human lead characters in the games that they designed. The implications of this finding suggests that there is gendered behaviour whether conscious or unconscious happening even at this age of a child's development. For the games industry, the implication is that adopting a gender inclusive approach to games design could create a more diverse population of those using digital games and those interested in a career in the sector. Ultimately, this would also impact on the public perception of the games industry [20] and wider discipline of computer science as a discipline making them more attractive across gender. Results also suggests evidence of an association between gender and feedback. Participants' evaluation of each other's games using the engagement factors showed girls were more interested in receiving feedback than boys.

This research provides a framework that shows how two learning theories can be integrated to facilitate learning for children using games design. The individual games the children created required a combination of creativity and some level of proficiency, which was supported by using an educational approach that combined elements from cognitive constructivism and direct instruction. Elements from each of the learning theories were utilised at each stage of the game design. For example, many of the children had played games before but had never built a game before. There was a need for step-by-step *structured instruction* to build competency in new knowledge learnt in order to enable children actively construct from what they previously knew (*prior knowledge*). The children were able to build accuracy through practice during *seatwork* and were able to explore their creative sides at individual paces by *applying what they had learnt*.These are all consistent with studies [18, 20] that advocate for combination of learning theories that are appropriate. The integrated framework created an effective experience for these young people. Classroom observations suggests they were engaged, alert, asked interesting questions, and wanted to spend more time on the activities. Their feedback also provided evidence of their learning from the process particularly with regard to careers in computer science and stereotypes. Overall this suggests this approach is effective. The approach also provides evidence to show that both learning theories are not mutually exclusive and can be effectively integrated.

X. LIMITATIONS AND FUTURE WORKS

The study is not without its limitations. The study is carried out on a small sample size; generalisation of findings is therefore to be approached with caution. However, this limitation does not undermine the contribution of an age appropriate games design application based on the integration of suitable pedagogical learning theories through a combined framework. Further studies can adopt a larger sample size to evaluate and tease apart the contributory effects of the different elements of the pedagogical framework in game based learning for young children. Although this research is primarily focused on generating interest and uptake of computer science, this integrated pedagogical framework could be adopted to generate interest and uptake in other subject domains using a practical application such as games design. This would demonstrate further evidence of the usefulness of this framework in other contexts.

XI. CONCLUSION

This research contributes to conversations and research in digital games for learning, computer science, STEM education and research on pedagogical theories. It provides practical application of how young children are able to acquire complex knowledge of the games design process through scaffolding using elements of the two learning theories and an age appropriate approach to generate interest and improve engagement with computer science. The research also provides an evidence base of links between educational theory, research on technology in education and aspirations of young people and practical application in an educational context that can provide a strong foundation for further work in this area.

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