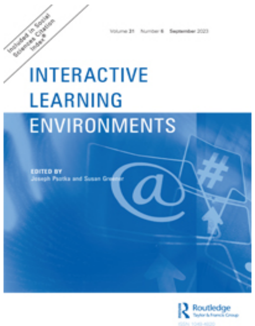

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Improving computational thinking: the role of students' networking skills and digital informal learning

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Improving computational thinking: the role of students' networking skills and digital informal learning

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ABSTRACT

Many professionals consider computational thinking an essential skill in the twenty-first century. Furthermore, some studies demonstrate that computer-based networking skills and digital environments can improve computational thinking. A challenging question to be addressed is whether informal learning in a digital context is related to computational thinking and whether it could mediate the role in networking skills and computational thinking. This study addresses the potential relationship between higher education students' computer-based networking skills and their computational thinking by means of the mediation of digital informal learning. The study sample comprised 351 students at Shiraz University in Iran. The results, found through structural equation modeling, indicated that networking skills positively and significantly related to students' digital informal learning and computational thinking. In addition, digital informal learning was considered a mediator between networking skills and computational thinking. In conclusion, educators and policymakers should consider the role of digital informal learning alongside networking skills to improve computational thinking skills.

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Digital informal learning; networking skills; computational thinking; higher education

1. Introduction

Due to ongoing changes in the way education is conducted, specifically the transition from traditional classroom settings to more pervasive online learning, concern for the development of computational thinking (CT) skills in the digital world is becoming increasingly more important for students (Lyon & Magana, 2020; Papadakis, 2022; Tsai & Tsai, 2018). Osio and Maxi (2020) even posited that CT is now an essential skill for survival in the digital world that is with us to stay. CT refers to possessing the knowledge, skills, and attitudes towards computer use (Korkmaz et al., 2017) for solving problems (Presser et al., 2023), and is likely to be associated with interpersonal computer communication, especially students' communication and networking skills. Networking denotes the ability of individuals to create, maintain, and use interpersonal relationships to facilitate resource mobilization (Wolff & Moser, 2010). So, interpersonal relationships and collaborative learning have a lot to contribute to educational activities involving CT (De Jesus & Silveira, 2022).

Researchers have both directly and indirectly investigated the relationship between networking skills and CT in various studies (Boholano, 2017; Mvalo, 2019; Yunus et al., 2012). Networks are platforms in which conversation and networking can take place, and tacit knowledge can be created through social interaction among individuals (Hearn & White, 2009). Thus, these networks can

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enable informal learning (Mehrvarz et al., 2021) for learners. Students are likely to develop their networking skills in informal digital settings. Digital informal learning emerged to address the challenges posed by the inefficiencies of conventional formal learning in adapting to new situations and the need for innovative learning methods (Yan & Fan, 2022). The importance of informal learning lies in its capacity to support and complement formal learning, while simultaneously enhancing cognitive, practical, and affective outcomes in self-directed student learning (Gramatakos & Lavau, 2019). In other words, digital informal learning is more motivating for students due to providing a flexible environment (Heidari et al., 2021; Meyers et al., 2013) and new opportunities to learn anytime and anywhere (Astuti & Setiawan, 2023). As a result of technological and information advancements, attention towards digital informal learning has increased (Astuti & Setiawan, 2023). In general, one of the major concerns of higher education systems, especially in recent years in which online education has grown dramatically, is how CT instruction could improve in digital environments. Although various studies have been conducted in this regard (Boholano, 2017; Ehsan et al., 2021; Mvalo, 2019; Wei et al., 2021), the question is whether networking skills and digital informal learning environments could improve students' CT, especially through the mediating role of digital informal learning. In the present study, we report our findings in exploring this research question.

2. Literature review

2.1. Theoretical framework

The roots of the concept of computational thinking (CT) can be traced in constructivist learning theory (Ali & Yahaya, 2020; Cansu & Cansu, 2019). Based on this theory some programs such as LOGO (Papert & Harel, 1991), and Scratch (Brennan & Resnick, 2012) have been designed to improve students' CT (Cansu & Cansu, 2019; Moon et al., 2020). These programs were the first tools that focused on developing thought and creative programming learning in k-12 students (Rodríguez-Martínez et al., 2020; Zhang & Nouri, 2019). Papert, like Piaget, believed that knowledge is actively constructed in a person's interaction with the world around them. This process is reinforced by providing opportunities to engage in practical exploration (Ackermann, 2001).

One of the notable frameworks of CT is ISTE (International Society for Technology in Education) (2008) which is used in the research discussed in this article and consists of five sub-categories: creativity, algorithmic thinking, critical thinking, problem-solving, establishing communication, and cooperation, defined as follows. Creativity refers to creating and developing novel solutions and ideas to solve problems in a specific context (Abraham, 2013; Sadak et al., 2022). Algorithmic thinking is indicative of the skills of understanding, applying, assessing, and producing algorithms. Critical thinking denotes the explanation, interpretation, analysis, and objective evaluation of an issue in order to judge and make decisions. Problem-Solving refers to identifying the causes of a problem as well as identifying, evaluating, prioritizing, and selecting appropriate solutions (Elia & Margherita, 2018). Cooperation is a learning method in which individuals collaboratively analyze a particular issue from various aspects in small groups (Veenman et al., 2002).

CT can be developed through factors like communication and networking skills (Alsaleh, 2017; Rosiyanah et al., 2019). In this article, we use the term "networking" to refer to the capacity to make and develop connections with others in the informal online context. In other words, "networking skill" is the process of building and maintaining relationships with others who can help in achieving goals (De Janasz & Forret, 2008). So, a networking skill like CT is rooted in the constructivist approach. One of the theories that can be proposed as the basic theory of networking is Vygotsky's view of learning in the constructivist approach (Muijs et al., 2010). Vygotsky believed that learning relies on collaboration, meaning that interaction leads to scaffolding that leads people to achieve more than they could individually (Vygotsky & Cole, 1978). Knowledge for Vygotsky happens in actions and interactions with the environment and others (Muijs et al., 2010).

In addition to networking skills, digital informal learning can enhance students' CT (García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019). Learners' digital literacy goes beyond familiarity with specific technologies and includes comprehensive skills to implement and use technologies in problem-solving contexts (Meyers et al., 2013), which is closely related to learners' CT (Moon et al., 2020). He and Li (2019) defined digital informal learning as a dynamic informal learning process with digital technologies, which includes varied aspects of actual learning behavior, including cognitive, meta-cognitive, and social and motivational learning. Based on the tenets of cognitive learning, students increase their knowledge and understanding of issues by using digital technology in informal learning contexts (Mayer, 1998).

As we have seen, this variable is a combination of cognitive, social, and motivational dimensions. One of the underlying theories in the combination of cognition and motivation in the social environment is the theory of social constructivism which allows us to look at both the cognition and motivation functioning of the individual in learning environments (Sivan, 1986). Social constructivist theory is primarily a paradigm for cognitive development (Sivan, 1986) and is adaptable to conceptualizing motivation in learning situations (Sivan, 1986). Vygotsky believed social constructivism is a student's interaction in a learning environment along with a personal critical thinking process (Kalina & Powell, 2009). Also, learning systems need to consider psychological aspects, such as motivation, as part of the scaffolding process (Luckin & Du Boulay, 1999).

2.2. The relationship between networking skills, digital informal learning and CT

Researchers have found that CT can increase and improve under the influence of various factors, including networking skills and communication with others (Alsaleh, 2017; Rosiyanah et al., 2019). Some studies have indirectly examined the relationship between CT and networking skills (Boholano, 2017; Mvalo, 2019; Yunus et al., 2012). As a case in point, Mvalo (2019) in a mixed-method study of 69 students and 14 lecturers at a UK university, concluded simulation software was a convenient platform to facilitate students' CT skills. In Mvalo's study, students were able to demonstrate the concepts of abstraction, analysis, and generalization utilizing problem-solving tasks by means of simulation software.

In addition to networking skills, research has also exhibited that digital informal learning is an appropriate setting for the promotion of students' CT due to being flexible and occurring away from the traditional classroom (García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019; Marty et al., 2013). In a study by Song et al. (2021), they examined the effects of novice learners' computer programming patterns on self-regulated learning, computational thinking, and learning performance in 105 South Korean senior undergraduate students. The results showed that programming patterns had a relation with self-regulated learning, computational learning skills, and learning performance when a computational technique is utilized. Shang et al. (2023) investigated the impact of a three-day robotics STEM camp program on the self-efficacy and computational thinking skills of 153 third- and fourth-grade elementary school students from three rural schools in China. The results showed that the robotics STEM camp program significantly improved both self-efficacy and computational thinking skills, particularly for students with prior experience in engineering-based activities and programming. In addition to these findings, some studies have highlighted the positive effects of games on improving students' CT skills. For example, Alfaro-Ponce et al. (2023) suggested that designing a digital citizen science game with consideration for the sub-competencies of complex thinking can help develop university students' computational thinking skills. Furthermore, a digital game-based learning framework for citizen science topics has the potential to increase engagement and teamwork among students in data collection and analysis, while building their knowledge, computational thinking skills, complex thinking competency, and sub-competencies. In another study, Zhang et al. (2023) investigated the impact of different learning approaches on the CT skills of grade-two primary school students in a rural area of China. They compared traditional lectures, Game-Based Learning (GBL) using a newly designed board game in classrooms, and GBL with parental involvement. Both GBL approaches significantly enhanced students' CT skills compared to the traditional approach.

Given the relationship between digital informal learning and the students' CT, Chuang (2015) concluded that digital informal learning environments (mobile applications) could enhance collaborative learning, and would be influential in developing students' thinking skills. Although some studies have addressed the relationship between digital informal learning and various dimensions of CT including thinking skills (e.g. Khlaisang et al., 2021), critical thinking (e.g. Huang et al., 2020; Sun & Looi, 2018), creative thinking (e.g. Yunus et al., 2012), and problem-solving (Korkmaz et al., 2017), just a few studies have directly investigated the relationship between digital informal learning and CT (multi-dimensional) (Ehsan et al., 2021).

As results have shown, students' networking skills can have a significant relation on their CT and digital informal learning. Moreover, digital informal learning can have a significant relationship with the students' CT. The question thus arises whether digital informal learning could play a mediating role between networking skills and CT.

Most studies in the literature have examined the relationship between networking skills, CT, and digital informal learning by focusing on the activity of students in social networks, benefits, or the outcome of networking skills (De Janasz & Forret, 2008). Studies that focus on networking skills in terms of the ability to create, maintain and use interpersonal relationships are scarce (Lee & Chen, 2017). Also, the relationship among these variables has been established in various age groups, few studies have been done on undergraduate students' CT (Peteranetz et al., 2020). Thus, on the basis of prior research, the research model (Figure 1) and the following research hypotheses were proposed:

H1. There is a positive and significant relationship between networking skills and the CT growth of students.

H2. There is a positive and significant relationship between networking skills and digital informal learning.

H3. There is a positive and significant relationship between digital informal learning and the CT growth of students.

H4. Digital informal learning plays a mediating role in the relationship between networking skills and the CT of students.

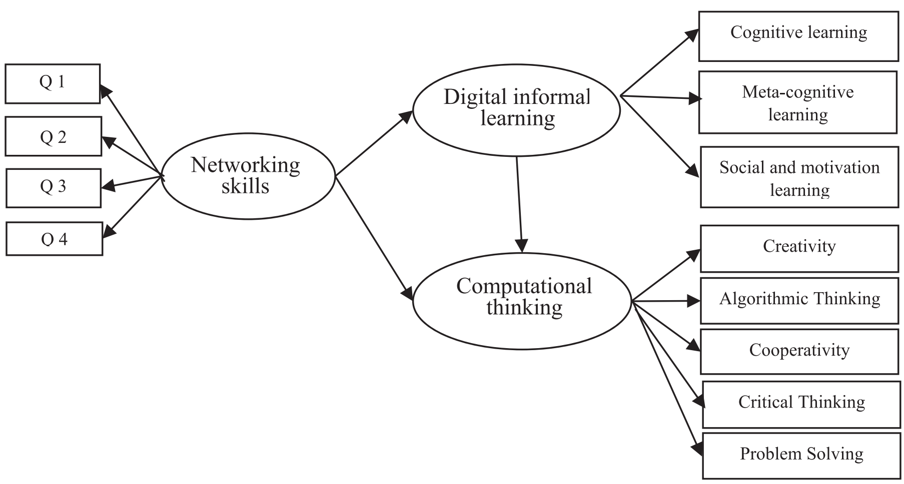

Figure 1. Proposed model of the relationship between NS, digital informal learning, and the CT investigated in this study.

3. Method

3.1. Study design and sample

This study employs a descriptive and correlational design utilizing structural equation modeling (SEM). The statistical population of the study comprised students at Shiraz University, one of the largest comprehensive universities in Iran. Out of 377 undergraduate and graduate students who were recruited to complete the questionnaires through a stratified random sampling method, 351 questionnaires were returned (94% response rate). The demographic information of the sample revealed the following: 38.5% ($n = 135$) were male and 61.5% were female ($n = 216$). Furthermore, 68.9% ($f = 242$) were undergraduate, 23.4% ($f = 82$) were master and 7.7% ($f = 27$) were Ph.D. students.

3.2. Measures

3.2.1. Networking skills

Students' networking skills were assessed via four questionnaire items (Ferris et al., 2005) using a 5-point Likert scale (1 = strongly disagree and 5 = strongly agree). For instance, one of the four items was: "I am good at building relationships with influential people" (Appendix 1). This questionnaire was tested on students by Lee and Chen (2017). Based on Lee and Chen's (2017) study, the validity of this scale is optimal, and its reliability was reported based on the Cronbach's Alpha coefficient of 0.87.

3.2.2. Digital informal learning

Students' digital informal learning was measured by means of He and Li's (2019) questionnaire. It has 12-items, for example, "I often use digital technologies to expand knowledge of the discipline" (Appendix 1). This questionnaire was based on a 5-point Likert scale and included 3 dimensions of cognitive learning (4 items), social and motivation learning (4 items), and meta-cognitive learning (4 items). The validity of this instrument was favorable and its reliability based on Cronbach's Alpha coefficient on Belgian students was 0.79, 0.80, and 0.83, respectively (He & Li, 2019).

3.2.3. Computational thinking

Students' CT was measured through a questionnaire designed by Korkmaz et al. (2017). This scale includes 29 items with 5-point Likert scale. One of its items is "I trust that I can apply the plan while making it to solve a problem of mine" (Appendix 1). This scale has 5 dimensions including creativity (8 items), algorithmic thinking (6 items), co-operativity (4 items), critical thinking (5 items), and problem-solving (6 items). The validity of this scale was optimal and its reliability is also optimal based on Cronbach's Alpha coefficient for all dimensions of creativity (0.84), algorithmic thinking (0.86), co-operativity (0.86), critical thinking (0.78), and problem-solving (0.72) of the whole questionnaire (0.82).

3.3. Data analysis

In this study, structural equation modeling (SEM) was employed to investigate the data from the study, using SPSS software (version 25) and AMOS (version 24.0). In order to evaluate the fit of the measurement model and the structural model of chi-square (χ^2), the chi-square/df, the incremental fit index (IFI), the comparative fit index (CFI), and the root mean square error of approximation (RMSEA) (Hooper et al., 2008) were implemented. The acceptable level of indicators was χ^2/df ratio <3, IFI and CFI > 0.90, and RMSEA <0.07 (Hooper et al., 2008; Hair et al., 2010, Kline, 2015). In addition, to investigate the mediating role of the digital informal learning variable, a bootstrap method was used with 2000 resamples.

4. Results

4.1. Preliminary analysis

The results demonstrated that the means of various dimensions of networking skills, digital informal learning, and CT growth variables of students were high and equal to the average level (3) and in the third quartile (Q3). In order to evaluate the normality of the constructs, two criteria of skewness and kurtosis were employed. The results revealed that skewness and kurtosis of all variables were within an acceptable threshold, i.e. −2 to +2 (Hair et al, 2010). Therefore, the variables show a normal distribution to indicate a positive and significant relationship among all dimensions of networking skills, digital informal learning, and the students' CT (Table 1).

4.2. Measurement model

In order to evaluate the measurement model of the research, construct reliability and convergent validity were employed. Composite reliability (CR) and Cronbach's Alpha coefficients were used to evaluate the construct reliability, average variance extracted (AVE) and confirmatory factor analysis (CFA) were implemented to evaluate the convergent validity. The acceptable level of Cronbach's Alpha and CR values were considered higher than 0.7 (Fornell & Larcker, 1981). The acceptable level of AVE was considered above 0.5 (Hair et al., 2010) and the acceptable level of factor loading of each item in the CFA was above 0.3 (Buyukozturk, 2007). The results of evaluating the second-order measurement model exhibited that the factor load of CT variables was: the creativity dimension between 0.52–0.73, algorithmic thinking dimension between 0.55–0.90, co-operativity dimension between 0.69–0.84, critical thinking dimension between 0.63–0.73 and the problem-solving dimension between 0.60–0.73. In addition, for the digital informal learning variable, the factor load of the CL dimension was between 0.76 and 0.87, the meta-cognitive learning dimension was between 0.81–0.87, and the social and motivational learning dimension was between 0.79–0.86.

Hence, the factor loads of networking skills variables were between 0.46 and 0.85. The Cronbach's Alpha and CR values of all variable dimensions were above the acceptable level of 0.7. Accordingly, the measurement model had the desired reliability. The results of the AVE evaluation also signified that all dimensions except critical thinking, problem-solving, and creativity were higher than the acceptable level of 0.5 (Appendix 1). According to Fornell and Larcker (1981), if the AVE is less than 0.5 but the CR is higher than 0.6, the validity of a construct is acceptable. The fit index of this model was also acceptable ($\chi^2 = 1976.03$, $df = 868$, $\chi^2\ /\ df = 2.27$, IFI = 0.90, CFI = 0.90, RMSEA = 0.06).

In the first-order analysis, latent variables such as digital informal learning, NS, and CT were specified with all of their underlying dimensions. The results indicated that CR ranged from 0.79–0.93, the Cronbach's Alphas ranged from 0.78–0.95 and the factor loadings dimensions of the latent variables ranged from 0.43–0.95. Based on discriminant validity, the square roots of the AVE were greater than the correlation between each construct and all other constructs. Therefore, the discriminant validity was acceptable (Table 2). The model fit index was convenient ($\chi^2 = 132.9$, $df = 48$, $\chi^2/df = 2.76$; IFI = 0.96; CFI = 0.96; RMSEA = 0.07).

4.3. Structural model

We investigated the structural model using SEM. As presented in Figure 2, there was a positive and significant relationship between networking skills and the students' CT ($\beta = 0.29$, $p = 0.0001$). Therefore, the first research hypothesis is confirmed (i.e. there is a positive and significant relationship between networking skills and the CT growth of students). Moreover, there was a positive and significant relationship between the students' networking skills and digital informal learning ($\beta = 0.63$,

Table 1. Descriptive statistics, skewness, kurtosis, correlations among study variables.

Variables	*M*	*SD*	Skew	Kurt	1	6	7	8	9	10	11	12	13
Networking skills	3	0.94	0.11	−0.30									
Cognitive Learning	3.4	1.01	−0.17	−0.33	0.59**								
Meta-cognitive learning	3.39	1.02	−0.19	−0.48	0.51**	0.85**							
Social and motivational learning	3.42	0.98	−0.25	−0.28	0.55**	0.76**	0.84**						
Creativity	3.95	0.65	−0.41	−0.01	0.39**	0.42**	0.46**	0.51**					
Algorithmic thinking	3.12	1.10	−0.03	−1.10	0.29**	0.40**	0.39**	0.39**	0.42**				
Cooperativity	3.89	0.90	−0.74	0.25	0.36**	0.29**	0.32**	0.40**	0.44**	0.20**			
Critical thinking	3.82	0.79	−0.55	−0.47	0.38**	0.45**	0.45**	0.51**	0.63**	0.46**	0.50**		
Problem-solving	3.5	0.80	0.01	−0.18	0.46**	0.47**	0.46**	0.53**	0.59**	0.63**	0.51**	0.74**	

Table 2. Discriminant validity.

Variables	1	2	3
1. Computational Thinking (CT)	**0.73**		
2. Networking skills	0.56	**0.73**	
3. Digital informal learning	0.61	0.63	**0.91**

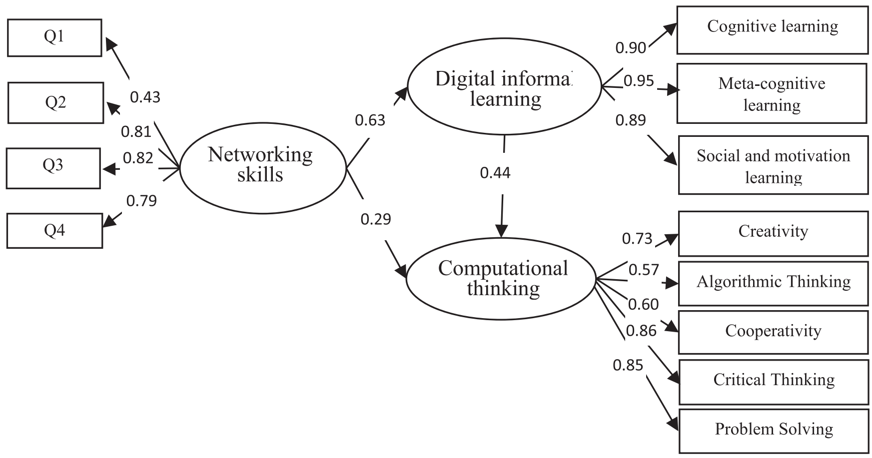

Figure 2. Research structural model.

$p = 0.0001$), this confirms the second hypothesis (i.e. there is a positive and significant relationship between networking skills and digital informal learning). The results also demonstrated that there was a positive and significant relationship between the students' digital informal learning and improving their CT ($\beta = 0.44$, $p = 0.0001$). Thus, the third research hypothesis is also confirmed (i.e. there is a positive and significant relationship between digital informal learning and the CT growth of students). The structural model fit index was acceptable ($\chi^2 = 132.90$, $df = 48$, $\chi^2/df = 2.76$; IFI = 0.96; CFI = 0.96; RMSEA = 0.07).

4.4. Mediation analysis

The Bootstrap method with 2000 resamples was employed to investigate the mediating role of digital informal learning in the relationship between students' networking skills and their CT. The direct relation of networking skills on the improvement of CT was $\beta = 0.29$, $p = 0.0001$. The indirect relation of networking skills on the students' CT with mediating role of digital informal learning was $\beta = 0.27$, $p = 0.0001$ and its confidence interval was within the range of 0.16 and 0.41. Therefore, the fourth research hypothesis is confirmed too (i.e. digital informal learning plays a mediating role in the relationship between networking skills and the CT of students).

5. Discussion

This study aimed to identify the mediating role of digital informal learning on the relationship between students' networking skills and CT. The first hypothesis put in this study, "there is a positive and significant relationship between students' networking skills and their CT," was confirmed. This indicates students who can make networks and communicate more frequently with influential people can collaborate better with professionals, use their experience, and increase their CT. As one of the constructivists in CT skills, Papert believed that knowledge is actively constructed in a person's interaction with the world around them (Papert & Harel, 1991). So, networking and cooperation with others provide students with more access and opportunity to interact, plan and gather information, and exchange ideas to improve their thinking skills. Interacting with others helps to solve problems and increases creativity (Lu et al., 2019; Yunus et al., 2012). Frequent studies have both directly and indirectly supported this hypothesis. For instance, Mvalo (2019) in a mixed methodology with qualitative methods examined the influence of simulation software to facilitate the application and development of students' CT skills. Data revealed simulation software provided a convenient platform to facilitate the students' CT skills from the students and lecturers' perceptions. In another study, Wing (2008) stated that CT is better achieved with the use of technology and the formation of various information, communication, and social networks. Through networking skills, students can identify and communicate with influential and significant people, gain experiences, and receive information to achieve objectives and maintain resources (De Janasz & Forret, 2008; Lee & Chen, 2017; Palalić et al., 2019).

The results also support the second research hypothesis, showing that there was a significant relationship between digital informal learning and CT. This finding, directly and indirectly, is in line with the results of some previous studies (e.g. Kafai, 2016; Lewalter & Neubauer, 2020; Moreno-León et al., 2018; So et al., 2020). Researchers believe that by programming exercises, some factors related to digital informal learning, such as identifying an unclear problem (Wing, 2011), and evaluating its function (Ota et al., 2016) CT skills improve (Moon et al., 2020). Chevalier et al. (2022) concluded, in line with our findings, that educational robotics (ER) is increasingly utilized as a tool to develop CT competencies among learners. Furthermore, Bray and Tangney (2016) in a study on 54 students found that informal digital technologies could enhance thinking skills and behavior processes and would help build a positive attitude towards mathematics.

According to the third hypothesis of this study, the results revealed that there was a significant relationship between networking skills and digital informal learning. This indicates the students' rate of success in digital informal learning is associated with how efficiently they could utilize networking skills in various situations. This finding is in line with the results of some previous studies (e.g. García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019). Networking and communication reduce the extraneous cognitive load of students (Kirschner et al., 2018), and help them to find their solutions easily, expand their knowledge and control their learning process.

Considering the fourth hypothesis, this study examined the mediating role of the students' digital informal learning on the relationship between networking skills and CT. The mediating role of digital informal learning on the relationship between networking skills and CT was confirmed. That means the relationship between students' networking skills and CT strengthens through digital informal learning. The literature showed that online networking is a digital competency that is relevant to students' networking skills, and it involves building and maintaining social connections through online platforms such as social media, professional networks, and online communities. (Falloon, 2020). Digital competencies that are relevant to students' networking skills include online networking, digital literacy, communication skills, and collaboration (Mehrvarz et al., 2021). So, online networking enables users to participate formally or informally in online communities for sharing ideas and co-production of knowledge. Informal learning through social media and online communities encourages professional development, which can improve students' digital literacy (DIL) (Gomez-Vasquez et al., 2021). Therefore, networking skills can affect DIL (He & Li, 2019).

On the other hand, DIL provides opportunities for students to engage in playful activities that develop algorithmic thinking skills (Juškevičienė & DagienĖ, 2018). By improving students' digital competence through DIL, students may also develop their computational thinking skills, which involve understanding, applying, assessing, and producing algorithms (Hunsaker, 2020; Juškevičienė & DagienĖ, 2018). To be more precise, the flexibility of informal environments increases students' motivation (Heidari et al., 2021; Meyers et al., 2013) and subsequently improves students' CT (García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019). In addition, students' CT skills improve through self-directed, self-controlled, and flexible learning (Song et al., 2021). So, when students learn how to search and use digital technologies and learn how to monitor and evaluate their learning (e.g. how using CT processes aligns with their goals), they will find more motivation to learn and share content with others. Furthermore, motivation (Vygotsky 1978; Luckin & Du Boulay, 1999) and informal learning contexts can scaffold students' learning and facilitate their career decision-making processes (Heidari et al., 2021).

Based on the given text, it can be concluded that DIL is a mediator between networking skills and computational thinking. The text suggests that networking skills can affect DIL, and DIL can provide opportunities for students to develop their computational thinking skills. Therefore, the relationship between networking skills and computational thinking can be mediated by DIL.

6. Conclusion, limitation, and implication

Although this research makes valuable contributions to higher education in terms of improving students' CT, it has some limitations. First, because of the difficult access to students in person, this study employed online self-reported scales to investigate the students' behavior. Although Greene (2015) stated that self-report instruments were a very reasonable method for examining student perceptions of their motivation and engagement while studying, this kind of measure might lead to subjectivity and bias. So, future studies should examine the actual test, together with the self-report test. Second, students' attitudes, abilities, and behaviors might change over time as they acquire new knowledge and experience. Future studies should examine the relationships among these variables through conducting longitudinal research. Further studies should be conducted in various cultures, countries, and universities to survey whether similar results are obtained.

This research also provides practical implications for both educators and students. Based on the positive relation of networking skills on the students' CT, and the lack of students' awareness of networking skills significance (De Janasz & Forret, 2008), it is recommended that educators emphasize the pivotal role of networking skills to students. Since digital informal learning has a relationship with students' CT, educators and policy-makers should consider students' cognitive and meta-cognitive skills when designing curriculum.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Prof. Bruce M. McLaren is an Associate Research Professor at Carnegie Mellon University and past President of the International Artificial Intelligence in Education Society (2017–2019). McLaren is passionate about how technology can support education and has dedicated his work and research to projects that explore how students can learn with digital learning games (also called educational games), intelligent tutoring systems, e-learning principles, and collaborative learning. McLaren's research with digital learning games, for instance, has shown that students can learn decimals better by playing a web-based game than by using more conventional technology (e.g. IJGBL 2017 paper; the "Decimal Point" website). McLaren's research with intelligent tutors investigates how students learn when presented with erroneous examples in conjunction with intelligent tutors on the web. Prof. McLaren has also investigated how erroneous examples can work synergistically with educational games to help students learn. McLaren has also conducted a series of experiments investigating how chemistry students learn when presented with worked examples, in conjunction with intelligent tutors, as well as polite hints and feedback. Finally, Prof. McLaren has a keen interest in and experience with collaborative learning and technology for supporting and analyzing collaborative argumentation. Prof. McLaren has researched and developed educational technology using AI techniques to help teachers moderate collaborative e-Discussions and online arguments. Prof. McLaren has over 190 publications (36 journal articles) spanning peer-reviewed journals, conferences, workshops, symposiums, and book chapters.

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Appendix

Confirmatory factor analysis, Cronbach's Alpha, CR.

Factors	Factor loading	Cronbach's Alpha	CR	AVE
Computational Thinking		**0.93**	**0.84**	**0.53**
Creativity (CTC)		0.83	0.82	**0.38**
CTC1	0.54			
CTC2	0.52			
CTC3	0.53			
CTC4	0.71			
CTC5	0.75			
CTC6	0.56			
CTC7	0.56			
CTC8	0.67			
Algorithmic Thinking (AT)		0.78	0.91	**0.68**
AT1	0.55			
AT2	0.85			
AT3	0.86			
AT4	0.90			
AT5	0.87			
AT6	0.85			
Cooperativity		0.87	0.87	**0.64**
C1	0.69			
C2	0.83			
C3	0.84			
C4	0.83			
Critical Thinking (CT)		**0.83**	**0.82**	**0.48**
CT1	0.73			
CT2	0.73			
CT3	0.63			
CT4	0.69			
CT5	0.67			
Problem Solving		**0.82**	**0.83**	**0.46**
P1	0.67			
P2	0.69			
P3	0.73			
P4	0.69			
P5	0.68			
P6	0.60			
Digital Informal Learning		**0.95**	**0.93**	**0.83**
Cognitive Learning CL		0.90	0.90	**0.71**
CL1	0.85			
CL2	0.87			
CL3	0.86			
CL4	0.76			
Meta-cognitive learning (MCL)		0.90	0.90	**0.69**
MCL1	0.81			
MCL2	0.83			
MCL3	0.87			
MCL4	0.82			
Social and motivational learning (SML)		0.89	0.89	**0.66**
SML1	0.81			
SML2	0.79			
SML3	0.86			
SML4	0.79			
Networking Skills (NS)		0.78	0.79	0.50
NS1	0.46			
NS2	0.73			
NS3	0.73			
NS4	0.85			