Students' Engagement in Inquiry-based Learning: Cognition, Behavior and Affect

Styliani K Kourti

Students' Engagement in Inquiry-based Learning: Cognition, Behavior and Affect

Styliani K. Kourti

University of Athens, Department of Mathematics, Athens, Greece; stellakour@gmail.com

The present study focuses on the constructs of students' engagement in Inquiry-based learning (IBL). We analyzed two mathematics classrooms, using videos and interviews with the two teachers. After recognizing the IBL phases, a synthesis of Kong, Wong and Lam (2003) and Liem and Martin (2012) models was made in order to determine each student's engagement, in the framework of the IBL. Then the constructs of three students' engagement were also studied in relation to the phases of IBL, trying to identify the type of engagement that prevails at each phase of IBL. According to the results 35 out of 47 students studied were highly engaged. All high achieving students were highly engaged, having all three constructs of engagement increased. Low achieving students with high engagement presented intense behavioral and affective engagement. There were also low achieving students that presented low engagement during IBL.

Keywords: Inquiry-based learning, engagement, affect, workplace.

Introduction

Over the last few decades, serious concerns have been expressed about the quality of teaching and learning in mathematics and science and the need for improvements in order to meet the increasing needs of society (Artigue & Blomhøj, 2013). Inquiry based learning (IBL) approaches are promoted in research and developmental programs in mathematics and science (Pedaste et al., 2015). Several research projects, such as, the European, Mascil project (https://mascil-project.ph-freiburg.de/), seek to diffuse IBL in science and mathematics teaching in primary and secondary education. Much of current IBL's research focuses on cognitive issues, communication, mathematical competence, tools and resources for planning or implementing inquiry, professional development and collaboration-based learning (Dreyøe, Larsen, Hjelmborg, Michelsen, & Misfeldt, 2018), and less on affect during IBL.

In the educational context, students' motivation and engagement play an important role in their achievement and their interest in school (Liem & Martin, 2012). Students' disengagement is a contemporary issue of mathematics education, as it may affect long-term development of our communities (Attard, 2012). Although many IBL projects showed some positive benefits for students' learning, engagement's complex and multifaceted construct may be the reason why little research has been done to study engagement in IBL context.

Therefore, we consider it necessary to study IBL in relation to students' cognition and affect, arguing that the use of IBL approaches can contribute to the increase of their engagement. This study focuses on the constructs of students' engagement while IBL approaches are adopted in mathematics teaching. The research questions are: Can the implementation of IBL affect students' engagement? Which constructs of students' engagement (cognitive, behavioral, and affective) appear and intensify in the IBL phases?

Theoretical Framework

Inquiry-based learning, according Pedaste et al.'s (2013), is a process in which learners construct knowledge by discovering new casual relations, formulating hypotheses and testing them through experiments, and making observations. An important characterization of IBL is the development of an inquiry cycle (the phases of IBL with their sub-phases, and their interactions), a concept that has various definitions in the research literature. Pedaste et al.'s (2013), bibliographic review and synthesis of 60 articles identified the exploratory cycle that includes the phases of orientation, conceptualization (questioning and hypothesis generation sub-phases), investigation (exploration, experimentation and data interpretation sub-phases), conclusion and discussion (communication and reflection sub-phases), while almost all phases are related to each other.

Motivation is a central concept of affect research, and it can manifest itself in knowledge, emotion and/or behavior (Hannula, Evans, Philippou & Zan, 2004). The structures of engagement and motivation are often used together and are very closely linked. Motivation is defined as people's energy and boost for learning, effective work and achievement of their full potential, while engagement is defined as behaviors that align with this energy and lead (Liem & Martin, 2012), but engagement is more complex than observed behaviors. Kong, Wong and Lam (2003) developed an instrument for detecting students' engagement in the mathematics classroom, which operates in three levels: cognitive, behavioral and affective engagement. Cognitive engagement involves the idea of recognition of the value of learning and the willingness to go beyond the minimum requirements, while behavioral engagement encompasses the idea of active participation and involvement in academic and social activities (Attard, 2012). Affective engagement implies a sense of belonging and acceptance of the goals of schooling, and is related to the notions of self-efficacy, expectation, interest, perceived control, and autonomy (Kong et al., 2003). Several studies have found that the three constructs of students' engagement do not work individually but support and complement each other in a cooperative way. Also, Liem and Martin (2012) developed the Motivation and Engagement Wheel, which is a multidimensional framework representing salient cognition and behavior pertinent to motivation and engagement, and offers a discrimination tool for cognitive and behavioral elements of engagement (see Liem & Martin, 2012, pp. 4-7).

Methodology

The context of the study and the process of data collection

The present study is a case study of two mathematics classrooms, conducted in Athens, Greece. The data used were videotaped lessons and semi-structured interviews with both teachers. The lessons were designed within the context of a European research project, Mascil (www.mascil-project.eu), that aims to support teachers in using IBL approaches into their teachings, and making connections to workplace (activities that involve authentic problems, and can be more or less similar to activities actually carried out by workers in the workplace with more or less use of authentic tools/artefacts).

A grade 10 class, (27 students, boys and girls, mixed cognitive dynamics, 15-16 years old), and a grade 11 class (21 students, boys and girls of mixed cognitive dynamics, 16-17 years old) were studied. Two videotaped lessons were analyzed in which the teachers used the "Drug concertation" task, from Mascil's platform, where students partly adopt the role of pharmacologist in finding out

how drugs work in the body, using mathematical models instead of experimenting in a laboratory (http://www.fisme.science.uu.nl/toepassingen/22038/). The grade 10 classroom was divided into seven groups of students, while the grade 11 classroom into five groups. Each group's students were chosen by the teachers, so that groups of mixed dynamics were created.

Both interviews with the teachers lasted about one hour. Teachers responded to questions about each student's performance and participation before and during IBL. Episodes related to students' engagement from the videotaped lessons were selected by the researcher and discussed with the teachers, and questions related to the IBL process were asked in relation to the selected episodes.

Data analysis

The groups formed in the classroom were the groups of our analysis. In order to facilitate this process, based on individualized students' data drawn from the interviews with the teachers, students were grouped into two groups. The group of high achievers includes students with a great interest in mathematics, a high cognitive mathematical level, active participation in the mathematics discourse in the classroom. The group of low achievers includes students with moderate, low or no interest in mathematics, medium or low cognitive level, low or no participation in the mathematics discourse in the classroom. One student out of 48 couldn't be studied because of inadequate data.

In order to distinguish IBL phases in each lesson, each teaching was studied at classroom level, using the videos and teachers' interviews, trying to identify the points of change of the phases, and their localization, based mainly on the cognitive processes of the students. Then, after determining the relationships between the phases and the sub-phases of IBL, the IBL framework for each of the teachings was formed, according to the pedagogical learning framework of Pedaste, et al. (2015).

A synthesis of Kong et al.'s (2003) and Liem and Martin's (2012) models was made, in order to determine students' engagement, in IBL's framework. Kong et al.'s (2003) model was used for the engagement constructs (cognitive, behavioral, and affective) enriching it with the sub-constructs of the Liem and Martin's (2012) model. The videos were observed and transcribed. Based on this scheme, the data of each classroom's video was coded student by student. Through this process, the coding scheme used for the analysis of each student's engagement is presented below in Table 1.

	Engagement	**Indicators**
Cognitive	Connecting with previous knowledge, Dependence on the teacher, Trying Examples, Comprehend question, Justification of arguments, Explanation to the other members of the group, Independent work , Dependent work, Memorization, Abstraction (limit notion intuitively), Superficial strategies, Passive	Questions, Completing peers' phrases, Exchange of ideas, Give directions explanations and information, Justification of an argument, Answer teacher's questions, Give information, Explain processes and justify, Question the teacher, Gestures
Behavioral	Attention, Persistence, Thoroughness, Participation, All over the task, Partial Participation, Surface participation	Body movements, Face expressions, Verbal expressions, Interaction with peers (verbal, body), Gestures

Affective	Anxiety, Uncertainty, Interest, Enthusiasm, Joy, Disruption, Boredom, Curiosity, Uncertain control, Failure avoidance, Anger, Goal achievement	Face expressions, Verbal expressions, Body Stance, Gestures

Table 1: The constructs of student engagement and their indicators

Recognizing the constructs of students' engagement was a complex methodological process, as the engagement is a multidimensional concept also related to the internal affective structures of each individual. An example of our analysis is illustrated below, concerning the engagement of a high achiever, in mathematics, student:

> Listening to the explanations of the other members of the group (behavioral- attention), he is crouched over his notebook (behavioral- all over the task), hitting his pencil on the desk and overcrowding his eyebrows (affective- anxiety and uncertainty). Using footnotes in a tooltip over the paper to help organize the presentation of the solution (behavioral- thoroughness). At the same time he says: "no, we do not have to do that because our teacher will not like it ... though it seems to me right (cognitive- dependence on the teacher and dependent work) ... I do not know what to do [puff and blow] (affective-uncertain control and anxiety) ... let's ask him to be sure he (referring to the teacher) knows better (cognitive- dependence on teacher, affective- failure avoidance)".

Then each student's engagement was evaluated as high or low based on the three constructs of engagement he had presented. Each of the three constructs was equally accounted for, for the above evaluation. High is recognized as the engagement of a student who has an intensified engagement in at least two of its constructs (cognitive, behavioral and affective engagement).

The constructs of student engagement were also studied in relation to the IBL phases, in three cases of students, trying to identify the type of engagement that prevails at each IBL phase. The first student (boy, grade 11) was a high achiever and presented high engagement, the second student (girl, grade 10) was a low achiever and presented high engagement while the third (girl, grade 10) was also a low achiever but presented low engagement. The students 1, 2 and 3 were typical representatives of their achievement groups and an overall picture of students' engagement in the IBL phases could be formed.

Results

The results of this research showed that both classrooms during IBL presented all IBL phases and sub-phases, except experimentation (investigation phase- no experiment was required to test the hypotheses), as well as reflection (discussion phase- limited time spent on this phase).

In grade 10, one of the twenty-seven students could not be analyzed because of inadequate data. Seven of twenty-six students presented low engagement, while the remaining nineteen presented high engagement. Seven of the highly engaged students were low achievers, while the other twelve were high achievers. Regarding the highly engaged, low achievers group, all of them had intense affective and behavioral engagement, but six of them had low cognitive engagement, as they were

only using superficial strategies. For the twelve highly engaged, high achievers, all three constructs, particularly cognitive, were intensified.

	Total	Highly Engaged	Cognitive engagement	Behavioral engagement	Affective engagement
Low Achievers	24	12	Limited	Intensified	Intensified
High Achievers	23	23	Highly Intensified	Intensified	Intensified

Table 2: Overall results of students' engagement

In grade 11, fifteen out of the twenty-one students presented high engagement while the remaining six students presented low engagement. Five of the highly engaged students were low achievers, while the other ten were high achievers. The highly engaged, low achievers had intensified affective and behavioral engagement while the cognitive engagement of three of them was low, since they were only using superficial strategies. All high achievers were highly engaged, having all three engagement constructs intensified, especially their cognitive one. Table 2 presents aggregated results of students' engagement.

The constructs of engagement in the phases of IBL: Three cases of students

Then, an attempt was made to identify the intensified constructs of students' engagement in each IBL phase, of three representative cases of students. The findings are summarized in Table 3 (where CE, BE and AE are cognitive, behavioral and affective engagement respectively, and with bold are the intensified engagement constructs of each phase).

Student 1 was a highly engaged, high achiever. He was highly affective engaged in orientation phase, demonstrating interest and enthusiasm for the activity. In conceptualization phase, his behavioral engagement was intense, as he was constantly all over the activity, paying attention and showing persistence. Affectively, in the same phase, he was very enthusiastic about both the context and the solution process of the task. In investigation phase, all three constructs of his engagement were intensified. Of particular interest was the development of his cognitive engagement as he addressed questions of understanding both to the teacher and to the other members of his group, he used trying examples, connected the old knowledge with the new one, and almost at the beginning of the investigation phase he realized, through the diagram, that the function tended to be limited in a number, and later he explained his thought to both the professor and the rest of the group, being very joyful about it. In conclusion phase, his cognitive engagement was intense as he tried to explain his thoughts to the rest of the group using arguments. Finally, in discussion phase, all constructs of his engagement were intensified, as he revived the entire previous inquiry process. While he was communicating his group's results to the rest of the class, he was very enthusiastic about their solution.

Student 2 was a highly engaged, low achiever. She, in the orientation phase, did not seem to have any interest in the activity, and she also presented signs of boredom. In conceptualization phase, her curiosity was triggered, so she began to ask questions of understanding the activity, while at the same time she was paying attention. In investigation phase and in conclusion phase, all three

constructs of her engagement were much intensified, and were kept unabated throughout these phases. Affectively, she was very interested and curious in getting involved with the task. Feeling uncertain control, she tried to explain to the other members of her group her understanding of the solution given. Finally, in the discussion phase, during which the group presented its results to the rest of the class, the student's 2 engagement was limited, while only her behavioral engagement was intensified, leaving some other members of her group to present the cognitive part.

	Student 1 **High Engagement**	**Student 2** **High Engagement**	**Student 3** **Low Engagement**
Orientation	CE: Comprehend questions BE: All over the task **AE**: Enthusiasm, Interest	CE: None BE: Attention **AE**: Boredom	CE: None BE: Partial Participation AE: Boredom
Conceptualization	CE: Comprehend questions, Trying examples **BE**: All over the task, attention, Persistence AE: enthusiasm, interest	CE: Comprehend questions BE: Attention **AE**: Curiosity, Interest	CE: Passive BE: Partial participation, Attention **AE**: Curiosity
Investigation	**CE**: Connecting with previous knowledge, Trying Examples, Comprehend question, Justification of arguments, Explanation to the other members of the group, Abstraction (limit notion intuitively) **BE**: All over the task, attention, Persistence, Participation **AE**: Interest, joy, uncertain control	**CE**: Comprehend questions, Trying examples, Connecting with previous knowledge **BE**: Attention, Thoroughness, Participation **AE**: interest, curiosity, uncertain control	CE: Passive **BE**: Partial participation, Attention AE: Curiosity
Conclusion	**CE**: Connecting with previous knowledge, Explanation to the other members of the group, Abstraction **BE**: Attention, Participation AE: Interest, joy	**CE**: Trying Examples, Explanation to the other members of the group **BE**: Attention, Participation, Thoroughness **AE**: Interest, Curiosity	CE: Passive BE: Partial participation AE: Interest, Boredom

Discussion	**CE**: Connecting with previous knowledge, Explanation to the classroom, Abstraction **BE**: Attention, Persistence, Participation **AE**: Interest, enthusiasm, joy	CE: Connecting with previous knowledge **BE**: Attention, Thoroughness AE: Interest	CE: Passive BE: Attention AE: Disruption, Boredom

Table 3: The constructs of student engagement in the stages of IBL

Student 3 was a low achiever who presented overall low engagement, especially in the phases of orientation, conclusion and discussion. In conceptualization phase she showed interest and thus her affective engagement was intensified, while in investigation phase her behavioral engagement was intensified as she showed some attention and partial participation. In all phases she was cognitively passive, like the other students of this case. Affectively, the students of this case seemed to be bored during the whole activity, except from conceptualization phase, during which some of them showed a bit of interest, or curiosity, mainly for the context of the activity.

Discussion

According to the results 35 out of 47 students were highly engaged. This may be due to the possibilities offered by Inquiry-based learning and teaching, as according to Artigue and Blomhøj (2013), it becomes a potent tool in personal and collective response efforts of an important question, making these experiences not only unpublished but inspired and structural for the whole educational project.

The students of case 1 were cognitively highly engaged in the investigation, conclusion and discussion phases. This is probably due to the fact that IBL, on average, increases conceptual understanding in science, mathematics, engineering and technology courses (Freeman et al., 2014, as cited in Capaldi, 2015), while traditional teaching can lead to low levels of conceptual comprehension (Epstein, 2013, as cited in Capaldi, 2015). The students of case 2 were all highly engaged, especially in the investigation and the discussion phase. This may be due to the fact that these two IBL phases are relying on group-work and collaboration provides support for tackling difficult problems or concepts (Capaldi, 2015), which encourages students to be active participants in the construction of their knowledge. Yet several students in this group showed low cognitive engagement in the entire IBL process. This might be due their previous cognitive deficiencies, or to their dependence on their group's highly achieving students, in a cognitive and affective way.

Highly engaged students, of both cases 1 and 2, showed intense behavioral engagement and positive affective engagement. This may be due to the authenticity of the workplace activity, allowing them to realize the usefulness of their school mathematics education and redefining their motives. Students' positive affective engagement may be due to the dissociation of the IBL activity from their grade retention. Grade retention often leads to maladaptive behavior, impeding cognition (Liem & Martin, 2012), causing negative emotions (for example anxiety) about mathematics

education. All three constructs of engagement are interrelated (Kong et al., 2003), thus negative affective engagement relates to negative behavioral and cognitive outcomes, and vice versa.

But the results from students of case 3 showed that despite the opportunities offered by IBL to increase students' engagement, there are students who are not motivated by them, without this, however, rendering them ineffective, since the number of these students is small compared to our rest sample. These students, according to their teachers, have no interest for the lesson, do not participate and most of them are mathematically weak. This is probably due to affective variables, which can be seen as indicative of learning outcomes or as predictive of future success (Hannula et al., 2004) or failure. At this point, further research into the subject's discipline is necessary.

One of the limitations of this study is that its inferences were mostly drawn from (replicated) observations, and in a subsequent phase, it would be good to combine with personalized interviews with the students to deepen more the analysis. Finally, some critical questions for future research arise: Can the more frequent use of IBL approaches alter the engagement of weak learners? If so, which constructs of engagement could be affected and in what way the IBL cycle may change?

References

Artigue, M., & Blomhøj, M. (2013). Conceptualizing inquiry-based education in mathematics. *ZDM*, *45*(6), 797–810.

Attard, C. (2012). Engagement with Mathematics: What Does It Mean and What Does It Look Like?. *Australian Primary Mathematics Classroom*, *17*(1), 9–13.

Capaldi, M. (2015). Inquiry-Based Learning in Mathematics. In Emerald Group Publishing Limited (Eds.), *Inquiry-Based Learning for Science, Technology, Engineering, and Math (Stem) Programs: A Conceptual and Practical Resource for Educators*, 283–299.

Dreyøe, J., Larsen, D. M., Hjelmborg, M. D., Michelsen, C., & Misfeldt, M. (2018). Inquiry-based learning in mathematics education: Important themes in the literature. *Nordic Research in Mathematics Education*, 329–337.

Hannula, M., Evans, J., Philippou, G. and Zan, R. (2004). Affect in mathematics education-exploring theoretical frameworks. In M. Johnsen Høines and A. Berit Fuglestad (Eds.), *Proceedings of the 28th Conference of the International Group for the Psychology of Mathematics Education*, Bergen, Norway, Vol. 1, 107–136

Kong, Q. P., Wong, N. Y., & Lam, C. C. (2003). Student engagement in mathematics: Development of instrument and validation of construct. *Mathematics Education Research Journal*, *15*(1), 4–21.

Liem, G. A. D., & Martin, A. J. (2012). The Motivation and Engagement Scale: Theoretical framework, psychometric properties, and applied yields. *Australian Psychologist*, *47*(1), 3–13.

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational research review*, *14*, 47–61.