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Modification of nstudy Software for Supporting and Assessing Clinical Reasoning Skills in Equine Surgery

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ABSTRACT

nStudy, a web-based online learning program, was developed to bridge the gap between the classroom and clinic by developing the clinical reasoning skills of veterinary students. Literature-based clinical reasoning scaffolds were developed to adapt the design of nStudy to support and analyze the regulatory processes of clinical reasoning in the context of equine surgery. Twenty-three students from faculty of Veterinary Medicine, Damanhour University were recruited for this study. The integrated scaffolds and prompts of the clinical reasoning within *nStudy* were significantly correlated and predictive for students' learning gain. Process mining (PM) technique was applied to modeling sequences of clinical reasoning learning action patterns that have been recorded in log files. PM provided additional information on the effects of *nStudy* scaffolds that could not be revealed by a simple analysis of frequencies of learning actions. Using PM technique to deconstruct the clinical reasoning into component parts and processes can help the educator's assessment to focus on a learner's reasoning deficit and provide immediate feedback. The present study lays the groundwork for future research into developing the updated version of nStudy to provide the adaptive scaffolds necessary to foster the clinical reasoning of students' learning and assess the reasoning deficit of learners.

1. INTRODUCTION

Clinical reasoning is a crucial skill for all surgeons, regardless of their area of expertise. Clinical reasoning is an essential skill used by medical experts to solve complex and ill-structured problems met in the emergency, operating room, or the clinic (Meterissian, 2006). Skills of clinical reasoning not only help the surgeon to reach an appropriate diagnosis, they are also the key to preventing diagnostic errors (Graber, 2009; Modi et al., 2015).Regrettably, many novice learners lack effective processes of clinical reasoning. The emergent research consistently indicates that novice learners have difficulty in generating hypotheses, identifying diagnostic cues, and directing gathering of data, prioritizing the patient's problems, painting an overall picture of the clinical situation and formulating a management plan (Audétat et al., 2013; Cutrer, Sullivan, & Fleming, 2013; May, 2013; Scott Smith, 2008).Emerging studies in the field of medical education ascribe the deficits of clinical reasoning to poor self-regulated learning (SRL) processes for example poor planning, insufficient self-monitoring, and inadequate self-evaluation which are strong predictors of a range of performance indicators (Brydges & Butler, 2012; Kitsantas & Zimmerman, 2002; Rencic et al., 2016). SRL enables clinicians to heighten attention to their processes of clinical reasoning and decision-making through improving their cognitive (critical thinking) and metacognitive (reflective thinking) skills in clinical contexts (Higgs &

Jones, 2008; Kuiper & Pesut, 2004).As a result, medical education researchers have turned to theories of SRL—and, specifically, SRL microanalytic assessment techniques—to explore clinical reasoning from a process-oriented approach rather than in terms of aptitudes (Artino et al., 2014; Cleary et al., 2016; Durning et al., 2011). This is to understand and explain why and how some clinicians succeed while others do not (Durning et al., 2011; Rencic et al., 2016).

Our aim of this study was to evaluate a computer based self-regulated learning environment (CBSRL) called "*nStudy*" as a learning tool as well as a research tool to support and analyze regulatory processes of clinical reasoning of veterinary medicine students. Literature-based clinical reasoning scaffolds were developed to adapt the design of nStudy system in the specific context of equine surgery (Audétat et al., 2013; Bowen, 2006; Byron et al., 2014; Cutrer et al., 2013; Hoffman, 2007; Levett-Jones et al., 2010; May, 2013; Roberti et al., 2016; Scott Smith, 2008; Weeks & Dalton, 2013; Winne, 2011; Winne & Hadwin, 1998; Wu et al., 2014). *nStudy* provides learners with various tools such as tagging, linking bundles of information, searching, and so forth to construct scripts about clinical problems combined with existing record traces of learning activity. To identify and infer the processes underlying the high and low students' learning outcome, we applied process mining (PM) techniques to modeling sequences of learning action patterns — that is, a sequence of actions with high certainty — that have been recorded in log files. Thus, we can make inferences on learners' strategic processes (e.g., focusing on clinical tasks), and regulatory processes (e.g., planning how to do a task.). The following research questions have been designed :RQ1: How are students' clinical reasoning regulation actions using the *nStudy* correlated with their learning gains? RQ2: Is there a difference in process model of clinical reasoning regulation between low- and high- learning gains students?

2. MATERIALS AND METHODS:

2.1. *nStudy learning environment*

nStudy has 5 different scaffolds: a "Study view", a "Library view ", a "Hub view ", a "Map view " and a "Essay view ".

Study view

In the *Study view*, learners can study and create their artifacts such as bookmarks, quotes, notes with different templates, and terms in any web page and any online pdf. When text is selected in web pages and pdf documents, *nStudy* automatically displays a popup menu. Options invite the student to highlight the text and create a quote of the selection or create a note or a term (Fig.1). Each artifact that the learner creates stays attached to the location in which it was created. *Bookmarks* preserve the URL (Uniform Resource Locator) of the source of the information automatically when learners visit it. It enables instructors to determine the type of learners' search; effective goal-directed search (focused) or ineffective free one (unfocused). *Tags* index characteristics of the information according to the learners' preferred cataloging system or a fixed set of tags made available by a researcher e.g. pro, con, relevant, important and confused. It allows the learners to generate a system for identifying cues or key features of the case, cataloging information according to tasks, and so forth. *Quotes* highlight content in a source, providing a quick visual marker, and every quote's information is copied to a sidebar in the browser, creating a list of selections. It permits learners to direct and focus his/her data gathering and appropriately select the key features or cues that should allow him/her to generate diagnostic hypotheses. *Terms* (semantic qualifiers) are considered as mediators for problem representation building. *Terms* enable learners to build dictionary of medical concepts through transforming two or three of the attributes into more abstract qualities (e.g. 'Owner said that a horse had a problem like this before in the same joint. The student could transform it into a term 'Chronic monoarticular'). T*erms* form includes three fields: title, definition, and clarify. *Notes* allow learners to elaborate information according to their interpretations of it. Each note invites the learner to title and tag it, and it is automatically linked to a quote that prompted making the note. *nStudy* is pre-stocked with a variety of notes that provide a schema (template) according to which the learner can structure an annotation about the selected information (e.g., debate note, comment note, clinical note, decision note, treatment plan, investigation note, and differential script). Such schema provides standards for metacognitively monitoring comprehension and for elaborating information in ways that enhance its retrievability(Bruning et al., 2004).

Notes schema: (1) *Comment note (Plain note)*: It encourages learner to generate free explanations when reasoning through complex cases (Chamberland

& Mamede, 2015). Schema of the comment note contain one slot; my view. (2) *Debate note*: It allows learners to take a position on an issue, which provides opportunities for the development and justification of arguments and counterarguments, the identification of inconsistencies in reasoning, the reevaluation of initial arguments, and the resolution of differences between perspectives. Schema of the debate note contains 4 slots; claim, evidence, warrant, and limits. (3) *Decision note*: It assists learners in making decisions and guides retrospective reflection on learners' decision-making processes and outcomes. Schema of the decision note contains 3 slots; when, do, and otherwise do (Fig.2). *(4) Clinical note*: It instructs learners to summarize the clinical view in 1 or 2 sentences along with the reasoning for this view. Schema of the clinical note contains 2 slots; clinical viewpoint, and reason. (5) *Differential script note*: It instructs the learner to summarize the chief complaint of the patient in a summary statement and to then prioritize the list of diagnostic possibilities and compare them using the defining and discriminating features of each hypothesis. Schema of the differential script note contains 6 slots; chief complaint, diagnosis 1, diagnosis 2, diagnosis 3, what if I find, and the final diagnosis becomes. (6) *Investigation or Treatment plan notes*: It requests learners to prioritize and justify the top investigations or treatments and compare the supporting and disproving evidence for each. *What if*; as open-ended question probes learners to generate alternative hypotheses and to increase learners' awareness of cognitive biases such as an early impression or limits further workup or consideration of other investigations or treatments plans. Schema of the treatment plan note contains 6 slots prioritize and justify treatment plan, treatment 1, treatment 2, treatment 3, what if, and my plan becomes:

Library view

Library view supports browsing and filtering *nStudy's* artifacts by metadata and content within artifacts such as tags, type(s) of artifact, date last edited, or date last viewed and content (Fig. 3). Also, learners can organize artifacts in a folder structure. By clicking a link opens the artifact's source, scrolls to its quoted text within the artifact and opens the artifact itself. It helps learners to monitor and assess their performance and keep track of what goals have been addressed and what aspects of the task are pending.

Essays view

Essays view allows learners to create and finalize their product of a learning project such as a case report, or discharge summary via an html editor with features to format text and layout. Other artifacts can be incorporated into an essay by drag-and-drop or copy-paste operations. It also keeps attached to the location in which it was copied.

Hub view

Hub view (chat) forms are text records generated as two or many learners exchange information. nStudy's hub, where discussions take place, can be configured to provide roles (e.g., investigator, radiologist, surgeon). To educate learners about how to carry out a role, prompts are available that are keyed to each role. This helps educator to track learners' ability of data processing and determine learners' stage of the RIME framework (Reporter, Interpreter, Manager, and Educator).

Map view

Map view is a graphical representation of relationships (links) among artifacts (nodes in the map). Learners can create a new map by generating artifacts in a map "space" and linking them. Also, maps can be created or augmented after filtering artifacts in the library that have desired qualities (e.g., notes and terms created in the past week). Artifacts in a map can be grouped to form clusters, and artifact can be elaborated by showing its links to other artifacts. This helps learners to make connections between the different pieces of information, to integrate the patient's perspective and contextual factors to paint a picture of the clinical situation and adjust his/her investigation or management plan. Moreover, it could be used to assess the learners' clinical reasoning through providing a visual representing learners' thinking or knowledge organization.

2.2. Participants

Exploratory study participants were twenty-three student volunteers from the fourth-year of College of Veterinary Medicine, Damanhour University, Egypt. (Age mean= 20.2, SD= .48).

2.3. Course and Learning Task

The study was performed in the context of a veterinary science course dedicated to equine surgery. The topic was mainly about "Diagnostic analgesia of the equine digit"(Schumacher et al., 2013). As a learning task, the learners were asked to complete a reading assignment on "Diagnostic analgesia of the equine digit" and write a report document in the length of 1500-1800 words about the blocking strategy of the equine digit. Participation in this study was voluntary and the outcome was evaluated in terms of knowledge tests and was worth 5% of their final grade. The participants were asked to solve knowledge tests prior to the learning task. Then, the students were advised to use nStudy after watching the video tutorial on it for one hour and seek help if needed. They were asked to use the nStudy tool for 3 days on an individual basis to achieve their reading assignment and write a report. Students interacted with the article to bookmark and organize online resources, highlight and quote key points, take notes, define terms and write the final report document. Time-stamped trace data of participants' interaction with nStudy was collected for analysis. On the last day, participants took a post-test consisting of the same items as the pre-test.

2.4. Instruments

Students' learning outcomes were evaluated using pre-and post- knowledge test (a case-based test prepared by authors and consisted of 5 multiple choices and one short answer question). The pre-test and post-test were identical, but participants were not made aware of this fact until receiving the post-test. Log files or trace data collect precise time-stamped, very fine-grained data about operations learners apply in nStudy (e.g., highlighting, tagging, note-taking) and information operated on (e.g., text highlighted, tags applied, content contributed to a discussion). Log file traces consist of: 1) a user ID that obviously distinguishes the learners, 2) a time stamp that refers to the time when the action occurred, 3) a learning activity that refers to the actions performed by learners, and 4) content of learners' notes and summaries (Fig. 4). nStudy log file included six activities that were available for each student to perform: 1) view bookmark, 2) set/edit tag, 3) create quote, 4) create/edit note, 5) create/edit term, and 6) create/edit document.

2.5. Learning analysis

2.5.1. Learning activity in nStudy

The trace data logged by *nStudy* was collected. This resulted in a total of 23 log files including traces from students' activities recorded by nStudy. The trace activities from the 23 students over the course of three learning sessions included 6106 activities. These trace activities were used to identify why and how the learners use clinical reasoning learning tools. To focus on clinical reasoning regulatory activities, we combined the create and set actions to become 'Edit' action, for example 'create highlight with tag' and 'set highlight tag' aggregated in one category 'Edit tags' actions.

2.5.2. Process mining in nStudy

We applied PM techniques as a promising approach to modelling sequences of clinical reasoning learning actions that have been recorded in log files. In the current study, we used Fluxicon's Disco analysis software (https://fluxicon.com/disco/) to visualize and explore the temporal sequence differences of learning process between three examples of the lowest- and highest-learning gains students. We used the median value of the students' learning gains scores to determine the Highest and lowest learning gains students. The process models with 6 actions categories (Bookmark, Highlight, Edit tags, Edit term, Edit note, Edit document) were calculated and analyzed separately for the three highest-learning gain students a total number of 1593 actions and for the three lowest-learning gain students 237 actions. By using PM techniques to discover process patterns in SRL logging actions, the researchers assume that the present trace data— comprising temporally ordered action sequences— is directed by one or more mental processes, with each set of processes corresponding to a process model(Sobocinski et al., 2017; Sonnenberg & Bannert, 2015). Hence, as described by Durning et al., (2013) deconstructing the clinical reasoning into component parts and process can help the educator's assessment to focus on a learner's reasoning deficit and to provide on time feedback. Thus, assessment strategies or patterns that enable more direct exploration of learning processes without interfering with these processes (e.g., think-aloud), and offer advantages to our understanding of reasoning process.

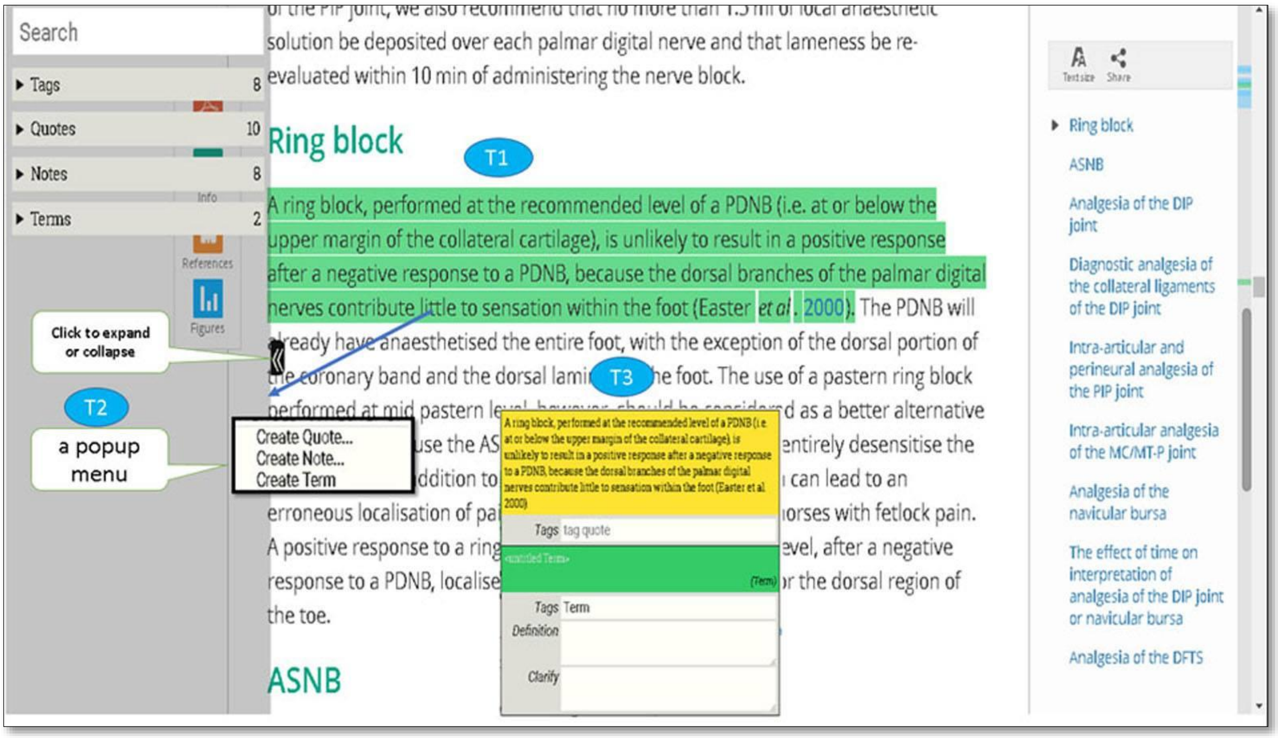

Figure 1: Steps to create a term in the study view of nStudy. When text is selected in web pages (T1), nStudy automatically displays a popup menu (T2). Options invite the student to create a term (T3).

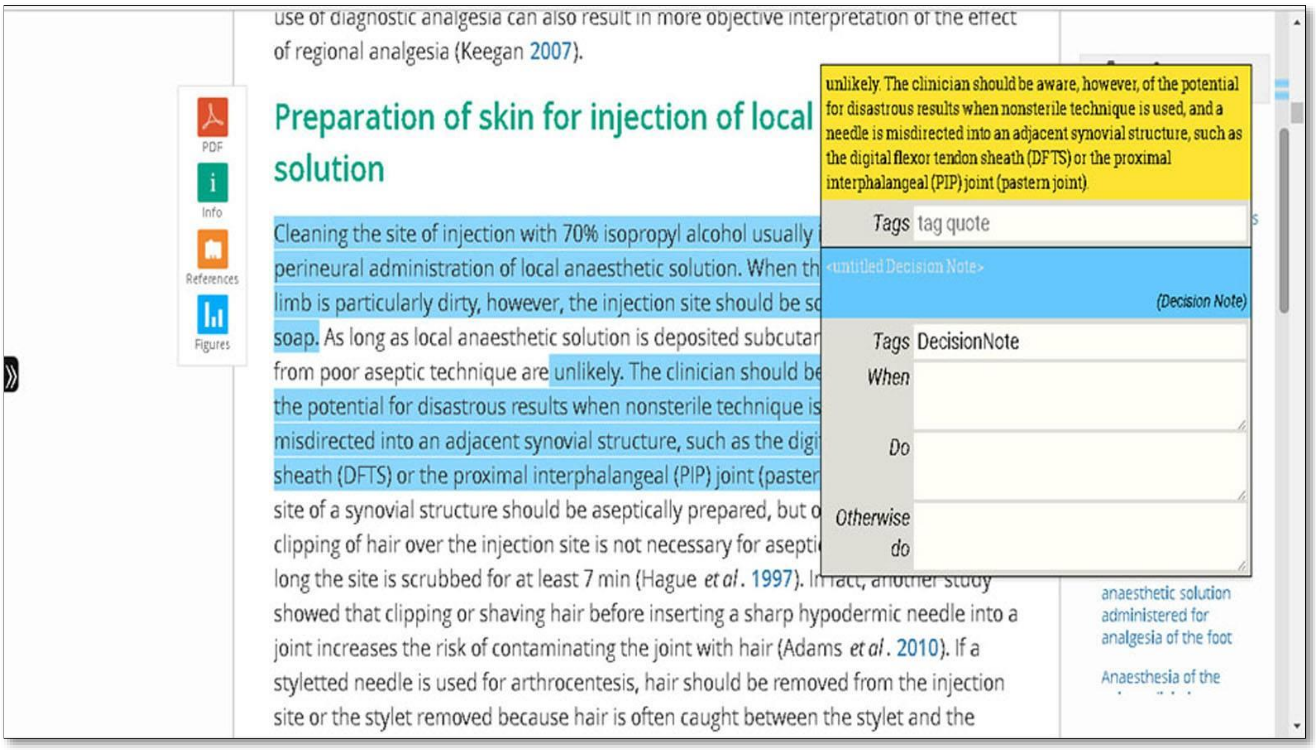

Figure 2: Schema of the decision note contains 3 slots; when, do, and otherwise do.

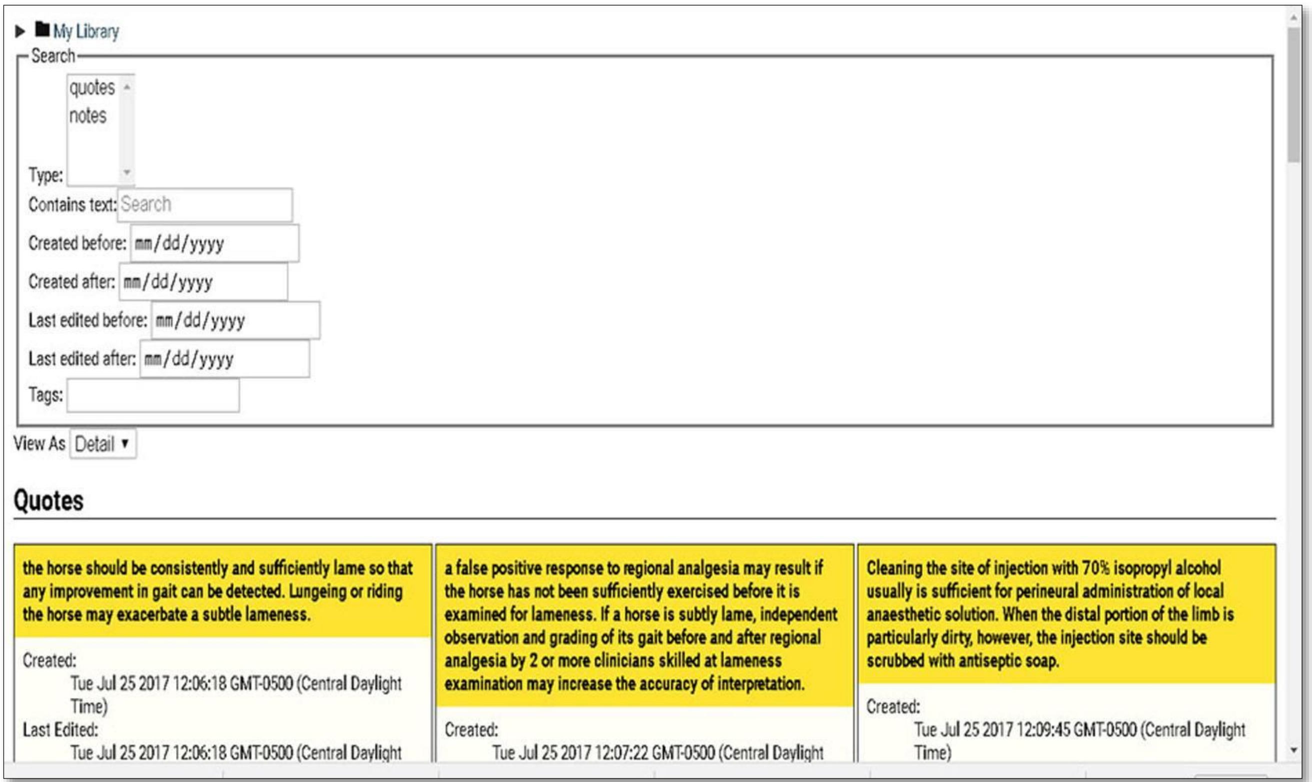

Figure 3**:** The library view of nStudy shows type(s) of artifact, date last edited, or date last viewed and content.

User Id	Time	Container	Action	Content
e4275400-625e-11e7-ab70-f9a8bb101f20	2017-05-06T21:02:11.125Z	https://www.ncbi.nlm.nih.gov/pubmed/9464910	Bookmark	
e4275400-625e-11e7-ab70-f9a8bb101f20	2017-05-06T21:10:00.327Z	https://www.ncbi.nlm.nih.gov/pubmed/9464910	create- clinical note	desensitizes the foot, the PIP joi pal
e4275400-625e-11e7-ab70-f9a8bb101f20	2017-05-06T21:16:58.776Z	Diagnostic analgesia of the equine digit (Proceedings)	Bookmark	
c7275400-625e-11e7-ab70-f9a8bb101f20	2017-05-07T15:57:02.881Z	ttps://research.vet.upenn.edu/SportsMedicine/LamenessExam/tabid/3697/Default.asp	create-highlight-with-tags	Important, addition of an antibiotic t inte

Figure 4: Log file traces consist of user ID, time, container, action type, and content.

3. RESULTS:

RQ1: How are students' clinical reasoning regulation activities using the nStudy correlated with learning gains? To answer this question, a linear regression was calculated with the frequency of students' clinical reasoning regulatory actions (Frequencies of bookmarks (mean: 155.78, SD: 143.41), highlighting (mean: 17, SD: 18.16, Notes (mean: 37.17, SD: 54.13), Terms (mean: 9.60, SD: 13.92), Documents (mean: 1.91, SD: 5.96), and Tags (mean: 44, SD: 77.18) as the predicting variable, and learning gains (difference between pre- and post-tests) as the predicted variable. The prediction model was statistically significant, $F(6, 16) = 11.566$, $p < .001$). The six variables considered in the model explain 74% of the variance of students' learning gains ($R2= .81$, Adjusted $R2= .74$). These results lend some support to the claim that students profit more when they regulate their clinical reasoning during the task.

RQ2: Is there a difference in sequential patterns of clinical reasoning regulatory activities between low- and high- learning gains students? To address this question, we used the median value of the students' learning gain scores to divide all the students ($n = 23$) into High and Low learning gain. Students with a learning gain greater than 11 were labeled high (n = 15) and those with a learning gain less than 10 were labeled low (n = 5). We employed a process mining technique (Günther & Van Der Aals, 2007) between three examples of the lowest- and highest-learning gains students. Fig 5&6 is a holistic view model with the main actions and their process relationships. Actions are represented by the square nodes which include the action name and its frequencies (i.e. Dark color for high frequencies while light one for low frequencies). The arrows indicate what category of actions pairs followed each other in the progressive online *nStudy* learning sessions. The frequency of the occurrence of the connections between the actions is presented next to each arrow. The dotted arrows show how often a particular action was the initiator or finisher pair in the data.

In Fig. 5, the model of highest-learning gain students contains 6 action categories, while the model of lowest- learning gain students contains 4 action categories (Fig. 6). We identify distinct action patterns that involve (Edit term), and (Edit document); those involving marking actions never occur in the lowest- learning gain students. In Fig 5, the model indicates that highest-learning gain students started by two patterns — that is, a sequence of actions with high certainty. Firstly, Bookmark→ Edit tags→ Create Highlight→ Edit note→ Bookmark. Secondly, Bookmark→ Edit tags→ Create Highlight→ Edit term. Furthermore, the process model contains a few loops with high certainty between two activities. Learners circle between Bookmark ↔ Edit document, Bookmark ↔ Edit note, and Create Highlight↔ Edit term. Moreover, it is thought-provoking that 'Create Highlight' relates to several other learning actions, meaning it earnings a central position in the structure of the process. Finally, the process model displays self-loops for all action categories, representing that an action can be done multiple times in a row.

In Fig 6, the process model represents one pattern with low frequency Bookmark→ Highlight→ Edit note→ Bookmark. Like the students in the highest-learning gain, 'Create Highlight' is also connected with several other learning actions, although this action category has a relatively low frequency. Edit tag action follows Edit note action once and is followed once too by Create Highlight unlike the process model of highest-learning gain students. Comparatively with highest-learning gain students, this process model shows one loop with strongly low frequency between two activities (only between Bookmark and Highlight). Only Bookmark action activities show self-loops.

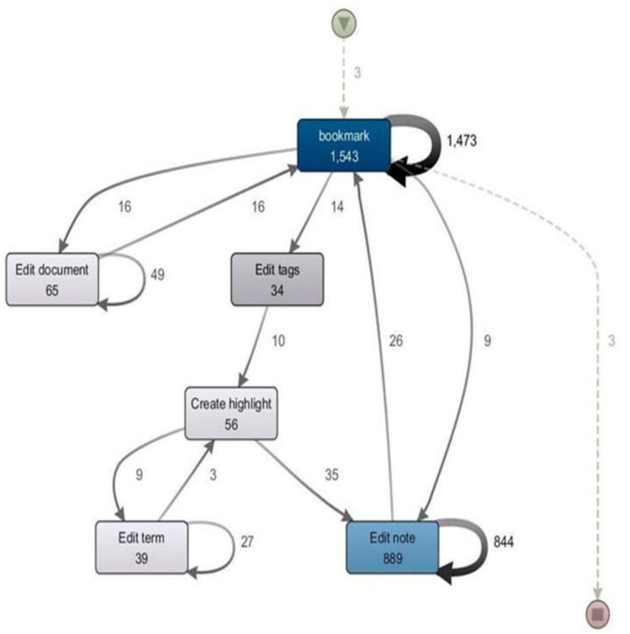

Figure 5: Process model of highest- learning gain students

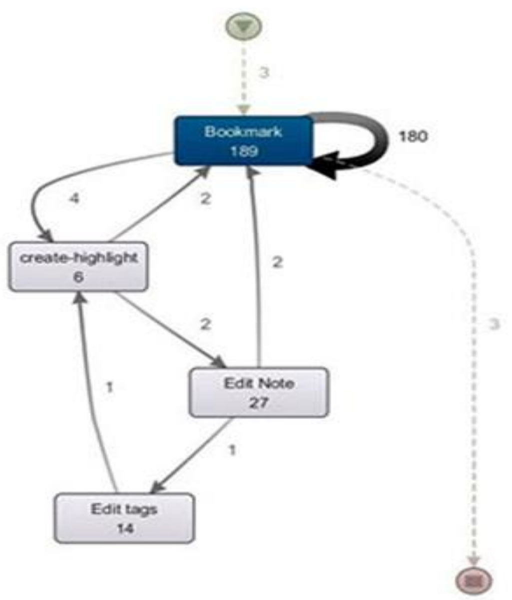

Figure 6: Process model of lowest- learning gain students.

4. DISCUSSION:

This study set out with the aim of assessing the importance of *nStudy*, a computer based self-regulated learning environment (CBSRL), to support and analyze clinical reasoning regulatory processes of veterinary medicine students in an equine surgery context. Regarding the first question, the current study found that integrated clinical reasoning scaffolds and prompts within *nStudy* are significantly correlated and predictive for learning gain. These results are likely to be related to the design of our scaffolds that depend on many strategies to support self-regulation of the clinical reasoning process such asking open ended questions, elaborating on answers, and monitoring an evolving understanding. This result is consistent with those of Artino et al. (2014); Bruning et al. (2004); Lajoie & Azevedo (2006); McCurdy et al., (2010) who showed metacognitive prompts enhance strategic navigation behavior (i.e., students visited relevant webpages significantly more often and spent more time on them) and transfer performance (i.e., students performed better at applying knowledge of basic concepts to solve prototypical problems compared with a control group. With respect to the second research question, the PM technique differentiated between specific sequential patterns in the learning process of the highest versus lowest learning gain groups. This process analysis provided additional information on the effects of metacognitive prompts that could not be revealed by a simple analysis of frequencies of learning actions. Our findings suggest that highest learning gain students switched between identifying the problems by surveying and collecting the problem cues then planning to process information by interpreting data to come to a deep understanding of information (bookmark followed by highlighting with tags and editing a lot of notes then returning to bookmark). An explanation for highlight a snippet of text in a web page is that the learner has standards for metacognitively monitoring information. When information satisfies those standards, the text is highlighted. Information not satisfying those standards is not highlighted. Learners, however, become aware that drawing a marker across text has little benefit in solving problems (Winne, 2017). Therefore, high learning gain students have a plan to be more deeply engaged on information through adding metadata for organizing the information (editing tags) before working deeply on the relevant information (highlighting followed by editing notes or terms). The lowest gain students, however, were using only one pattern with a high self-loop for bookmark. We also identified distinct action patterns that involve (Edit term), and (Edit document); those involving marking actions occur never in the lowest-learning gain students. A possible explanation for this result may be that terms (semantic qualifiers) are considered a conceptual scaffold to provide guidance for learners about what knowledge to consider during problem solving. It helps learners to articulate their own problem representations in an organized and summarized manner and recall elicited findings better (Bordage, 1994; May, 2013; Nendaz & Bordage, 2002). The document is considered a strategic scaffold to finalize the product of a learning project. It makes learners aware of different techniques for clinical reasoning and expose learners to the solution paths followed by other peers or experts (Azevedo & Lajoie, 1998; Lajoie et al., 1998; Lajoie et al., 2001). These findings corroborate the ideas of Nendaz & Bordage, (2002), who suggested that teaching semantic qualifiers is necessary specially during the process of knowledge acquisition and organization, and should be connected to the type of clinical problem. This connection facilitates the learner's retrieval of relevant information from memory.

4. CONCLUSION

In summary, this study shows the complex nature of the regulatory processes of clinical reasoning that follows the same loosely sequential and recursive process of SRL — collect cues, understand a patient problem or situation, plan and implement interventions, evaluate outcomes, and reflect on and learn from the process —, and correlates with learners' learning gain. These results will be used to develop the updated version of *nStudy* that can provide the adaptive scaffolding necessary to foster students' learning clinical reasoning and assess the learners' reasoning deficit.

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Phil Winne- lead developer/designer of *nStudy* software, financial support, and consultation of data analysis. Jim Schumacher: Experimental design, Consultation of design veterinary version of *nStudy*, and manuscript reviewing and editing. Ahmed Elkhamary- Project lead and coordinator, design of veterinary version of *nStudy*, contribute to experimental design, data analysis, tutorial video, literature review, and manuscript writing, editing, and submission. Mona Emara: Experimental design and data analysis. Our collaborator of North Carolina State university; Lauren Schnabel, Regina Schoenfeld, and Katie Sheats - consultation of design of veterinary version of *nStudy*.

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